Vulnerability of Landslide Hazard in Tropical Region

VULNERABILITY OF LANDSLIDE HAZARD IN TROPICAL REGION

DISSERTATION

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Preface

Like other South-East Asia countries, Vietnam is the country with mountainous terrain, complicated geological structure and high rainfalls. As the result, landslides occur regularly and seriously in mountainous regions, specially in rainy seasons. Landslide is one of the most dangerous and damaging natural disasters disturbing people living in and the socio-economic development of mountainous areas inVietnam.

Under the efforts to forcast and mitigate impacts of this phenomena on pepole, there were an ODA technical cooperation project funded by Japanese Government named as ''Development of Landslide Risk Assessment Technology along Transport Arteries in Vietnam''. The project's purpose is to develop landslide risk assessment technology in order to reduce landslide disasters along main transport arteries and on residential areas, totrain and develop the capacity for the effective use of this technology which has been implemented in Viet Nam. The expected outputs of project are (1) Preparation of integrated guidelines for the application of developed landslide risk assessment technology and capacity development by WG1 Joint Team of all groups, (2) Wide-area landslide mapping and identification of landslide risk area by WG2 Mapping Group, (3) Development of landslide risk assessment technology based on soil testing and computer simulation by WG3 Testing Group and (4) Risk evaluation and development of early warning system based on landslide monitoring by WG4 Monitoring Group.

This dissertation is results of the research by WG2 under the mentioned project for many years. The research covers the issues related to vulnerability of landslide hazard of slopes in tropical regions where the Central of Vietnam is a typical region stand for. The contents of research include providing methods to create landslide vulnerability map, proposing a new method for landslide classification, analyzing relationship between occurred landslides with causative factors and building a landslide susceptibility map for the reseached area. For application, a Landsilde Hazard

Vulnerability guidelines were established. I hope my study will contribute to regional landslide disaster management, minimize the damages of landslide phenomenon arising due to climate change to traffic systems particularly and the development of infrastructure in general.

I pay my sincere gratitude to the honorable every renowned Professors of Tohoku Gakuin University, Kyoto University Universities, and Forest Products Research Institute in Japan, many Officers and engineers, many Officers from Governmental and private sector, field officials, Japanese coordinators and especial thanks to Prof. Toyohiko Miyagi, Dr. Eisaku Hamasaki, Dr. Shinro Abe, Dr. Hiroyuki Yoshimatsu, Dr. Kazunari Hayahi who have contributed their outstanding efforts through their presentations, lectures, very hard site survey trips and training course in Vietnam and Japan for supporting me to finished this dissertation.

Abstract

Landslides are considered as a persistent problem in mountainous regions, especially distribute along transportation corridors. Landslides not only cause damages to properties (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 a rate of mountainous terrain up to 3/4 area of its territory with a steep sloped terrain due to earth's crust powerful tectonics. Moreover, it also has a complex geological structure and a tropical monsoon climate with the average annual rainfall from as much as 3,000-4,500mm/year in some regions. Consequently, Vietnam is a typical tropical country with the most serious landslide disaster in Southeast Asia and the Mekong sub-region.

Vulnerability of landslide hazard is refferred as the portability of slopes by landsliding. There are many causes of landslide vulnerability such as conditions of topography, geomorphology, geology, climate and artificial activities. Landslide vulnerability assessment is a large concept concerning to risk assessment on re-active landslides and landslide susceptibility. In order to mitigate the effect of this phenomenon to human life, landslide vulnerability assessment is requirement of fact.

The dissertation purpose is to develop a comprehensive method for the assessment of vulnerability to landslide risk in tropical regions based on providing a significant method for landslide classification, analyzing relationship of landslide phenomena with causative factors and creating a landslide susceptibility map for vulnerability of landslide hazard. Methodology of the dissertation is based on the conclusion as "for the landslides, the past and the present are the key to the future" (Varnes, 1984; Carrera et al., 1991, Hutchinson, 1995). In some cases together with others topography and slope formation processes, the cover of vegetation in tropical forest could delete their signals for recognition. So by this principle, occurred landslides will be recognized as much as possible, depending on capacity of human recognition. Under this hypothesis, landslides in the future may occur in the same

geological conditions, geomorphology and hydrogeology as it happened before. Therefore, to understand clearly about the movement of landslide in the past is very importance to assess landslide causes. From discovered landslides, the rules for landslide appearance will be studied then the prediction to land sliding sensitiveness is evaluated and forecasted.

The study area is a zone limited by a distance of 20 km offset to both sides from the center-line of HCM route, extending northwest and southeast between the latitudes of 16° 40'N and 15° 30'N and longitudes of 106° 15'E and 106° 50'E; extends to three provinces of Quang Binh, Hue, and Quang Nam of Vietnam. Through collecting occured landslides along 300km of the route since 2006 to 2015, in the Central of Vietnam.The research for vulnerability of landslide hazard was carried out through 16 reports and publisments. Five new reports and recently publishments are presented and discussed here for the dissertation.

The contends of dissertation includes (1) a new strategy for landslide prevention and mitigation for road in humid tropical region; (2) A prediction of Landslide Classification by pattern recognition of fuzzy inference method (3) Geological mechanisms of landslide generation in the study area ; (4) Landslide susceptibility mapping along the Ho Chi Minh route in the Central of Vietnam – an AHP approach applied to a humid tropical area and (5) Mitigation landslide hazard vulnerability Guideline.

From the damages of typical landslides in Vietnam on highway No. 37 (at Chen Pass), Son La Province; the Nam Non Bridge on the Western Route, Nghe An Province; at Hai Van Pass Station; on Highway No. 6 and along the Ho Chi Minh route in the central area, it is able to be recognized that the responding in face to this dangerous phenomenon seems to be quite passive. In the dissertation, a general method to prevent and mitigate landslides actively along roads in humid tropical region was also proposed. The core of the study is a new strategy for reduction affection of vulnerability of landslides, which was discussed by combination of the landslide risk assessment map, which is developed from risk assessment to occured landslides and the landslide susceptibility map, which is developed from the evaluation the sensitiveness to sliding of natural slope from landslide causative factors. The general method can contribute to the forecast, prevent and mitigate the negative impact of the landslide phenomenon for planning, land use, construction of infrastructure, ensuring the safety of existing traffic roads and mountainous residential areas in Vietnam. It can be applied to areas with similar conditions to the study area.

From 2012 to 2015, multi landslide investigations have been taken along Ho Chi Minh route in order to collect as many as occured landslides for assessment. According to Varnes classification, the occured landslides were classified. However, because of complicated phenomena and depending on point of observations, there were some landslide cases which had a non-consensus for classification. For landslide mitigation, a degree of risk valuation and the construction of prevention measures are necessary to prevent these landslide disasters. Therefore, it is necessary to execute a pattern recognition of different type classification. Cause of landslide having a various moving styles, but the analysis of this type classification is affected by the various factors. Therefore, we examine this analysis method of Landslide Classification in consideration of fuzzy nature. From results of study, we show that the weathering of the ground, a geological features and landslide scale are important factors through these analysis. The propose method is high technique analysis precision and could be applicated for similar assessment application.

In the Central of Vietnam, Ho Chi Minh Route (HCMR) runs from south to north along the border with Laos. In this area, HCMR is often closed due to numerous landslides during the rainy season. Thus, there is an urgent need to determine the generation mechanism of landslides and to conduct risk assessment. For this purpose, the area was chosen as one of the study areas for this project. This study focuses on landslides occurring at approximately 180 locations along the 150 km distance (linear distance) from Thanh My (west of Da Nang City) and the intersection with National Route 9 (west of Quang tri). The landslides are classified based on the type of movement in order to determine the triggering mechanism. The survey was conducted from 2012 to 2014. The type of landslide movement in this area differs significantly depending on whether if the area is Paleozoic metamorphic zone or Mesozoic sedimentary zone. The type of landslide movement in this area differs significantly depending on whether if the area is Paleozoic metamorphic zone or Mesozoic sedimentary zone. In metamorphic area, weak aspect such as schistosity, beddings, faults, and joints associated with geological structures become shear planes. Translational slides (wedge type) and rotational slide/flow (gulley type) occurs often in this area, with the infiltration of surface water and breaking of rocks by weathering as the cause. On the other hand, in Mesozoic sedimentary area, translational rock-slides are most common, where coal layers disrupted by fold structures function as the slip surface. It was shown that these landslides are not simply caused by heavy rain and weathering typical of the tropics, but are closely associated with geology, geological structure, development of rivers, and cuesta topography. This result shall be an important indicator in future study of vulnerability of landslide hazard.

To assessment the sensitiveness to vulnerability of the slope by sliding, a landslide susceptibility mapping along the Ho Chi Minh route in the Central of Vietnam was created. Ingeneral there are various possible causes for land sliding with complex inter–relationships. However, in practice a detailed assessment to find the main causes of each landslide is not feasible in most cases. The selection of causative factor for landslide susceptibility map is usually base on expert's subjective experience. In this study, to analyse landslide manifestation, causative factors are derived of slope angle, type of rock, fault density, distance to the road, land used and precipitation. Maps for causative factors were created, in which each one was divided in to classes. From position of 604 slope failures appeared along the Ho Chi Minh route a landslide distribution was build up. The sensitiveness to landslide of each classical zone of causative factor maps is calculated and then evaluated thought the value of number occurred landslide -NOL and density of occurred landslide DOL. These values were the result of comparison of landslide distribution map and each causative factor maps using GIS application. An analytical hierarchical process (AHP) is used to combine these maps for landslide susceptibility mapping. As the result, A landslide susceptibility zonation map with 4 landslide susceptibility classes, i.e low, moderate, high and very high susceptibility for land sliding, is derived based on the inventory map of observed landslide from 2006-2009. This map indicates that 82.66% total number of occurred landslide, which have been reported fall into highly and very highly susceptible zone. Even there was limited matter concerning relevant, scale and available data, the landslide susceptibility map of this study for corridor along this road is credible for landslide mitigation.

For landslide prevention, response and mitigation, a Landslide Hazard Vulnerability in tropical region a Guideline was proposed. The author approach is to answer for questions "What-Where-When-How''to landslides. Concept and classification of landslide in study area will be discussed for "What" question. Landslide moving mechanism is mentioned, in which the effect of the pore-pressure rise by raining is confirmed then the relationship between dynamic factor and displacement (signal of landslide recognition) is tagged for observation. As the result, basic data for landslide management and regional monitoring system are advised that will answer for “When” question. The integrated maps for landslide hazard vulnerability such as landslide inventory map, landslide risk assessment map, landslide susceptibility map and landslide hazard map are presented as basic tools to answer for “Where” question as site prediction. The application of research for landslide prevention, response and mitigation plan, in which landslide knowledge and tools were used to discuss for question “How”. This guideline will contribute for landslide hazard management as a basic document in the the Central of Vietnam.

Vulnerability of Landslide Hazard assessment is one very important issue in the "proactively prevent natural disasters" strategy of Vietnamese government. From landslides survey data in corridors of Ho Chi Minh route in center area of Vietnam, a basic data for occurred landslide was created base on three basic methods, which is commonly used for inventory maps as field recognizance to investigate landslide occurrences, collection of historic information of landslide and interpretation of landslide occurrences from aerial photographs. The relation of occured landslides distribution to causative factors such as topography, geomorphology, geology, climate and Artificial activities were studied. During the research time, the following matters including: new strategy for Landslide prevention and mitigation for road; the prediction of Landslide Classification by pattern recognition of fuzzy inference method; Geological mechanisms of landslide generation; Landslide susceptibility and Mitigation landslide hazard vulnerability Guideline for tropical region were discussed. The results of above studies could apply to similar tropical zone. However, vulnerability of landslide hazard assessment is large matters. Beside of above studies, Creation of Landslide Risk Assessment to occured landslides that using AHP or Fuzzy method not mentioned in this study should be the target of future researches. The studies in this dissertation will contribute to understand and mitigate the vulnerability of landslide hazard disaster in center area of Vietnam particular and humid typical tropical region in general.

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CHAPTER 1 – SIGNIFICATION OF THE RESEARCH

1.1 Landslide Situation in Vietnam

1.1.1 Natural Features

1.1.1.1 Topography

Vietnam is a country that has figure like letter "S", located on the eastern Indochina Peninsula between the latitudes 8°N and 24°N, and the longitudes 102°E and 110°E. It shares borders with China in north, Laos and Cambodia in the west and faces to Pacific Ocean on the east and south with its coastline is 3,444 km in length.

About 75% of its land area is mountainous, mainly located on the north and west area of Vietnam. The elevation of mountainous area is mostly lower 2000 meters above sea level. Fansipan Mountain, the highest peak (3,143 m) in Vietnam, stands in the north, whereas the Annamite Range, comprising lofty peaks of 2,000 m or higher, sits at the Laotian border in the central area of the country. The Hai Van Mountains in the central area divide northern and southern Vietnam. Vietnamese topographical map is presented in Fig1.1.

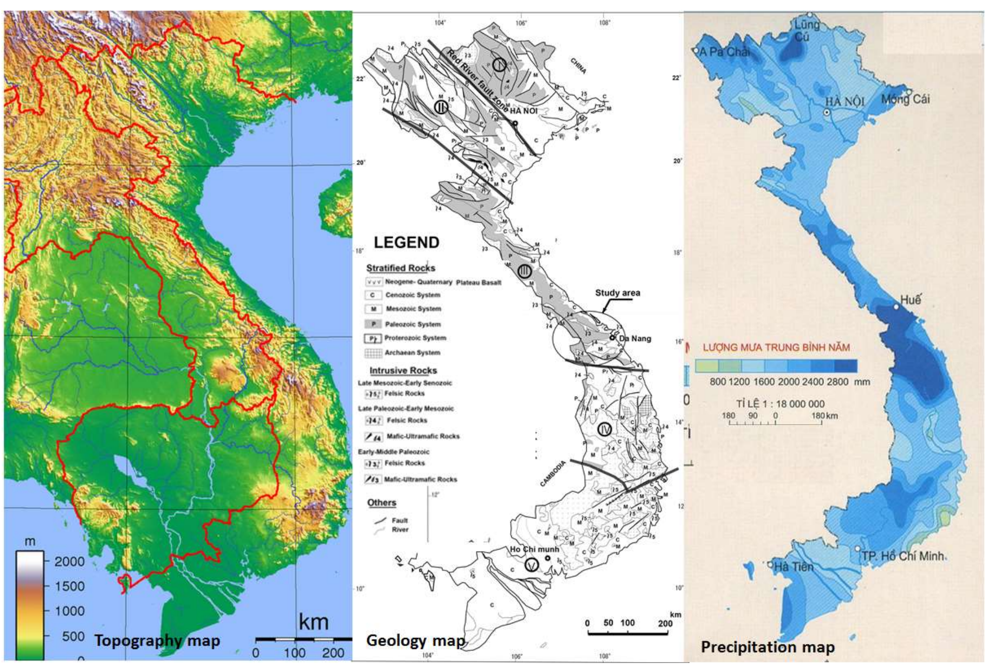

Fig. 1.1 Topography map (Atlas Vietnam) – Geology map (Tran,1995) – Precipitation map (Atlas Vietnam) of Vietnam

There are two main deltas locate in the north (Red River delta) and in the south

(Mekong River delta). The coastal plain arranged along the east is small, narrow and low economic value. Almost rivers, which run over the country from the northwest to the southeast, heading towards the Eastern Sea has a short length.

1.1.1.2 Climate

The Vietnamese climate is vary from north to the south caused by the figure country expand between different latitudes. It could be classifiable into three basic climate zones. Red river delta area has a tropical monsoon climate zone resembling the northern Vietnam climate. There are 4 clearly seasons in a year with average temperature range from 10 – 38° C. Mekong river delta area has tropical climate zone with 2 seasons in a year as dry and rainy season and temperature range from 21– 35° on average. Center area of Vietnam has transitional one. The average annual temperature is generally higher in the plains than in the mountains, and higher in the south than in the north.

Bordered by Pacific Ocean, Vietnam is influenced by the monsoon climate with the average annual rainfall from as much as 2,200mm to 3,000mm throughout the country and can reach to 4,000mm in some particular areas of the Central and located in one of the highest rainfall area in the world. The high precipitation zone, which covers on mountainous area, distributing on the northwest and the Central of Vietnam could make occurrence landslide seriously. The average annual rainfall map of Vietnam is presented in Fig 1.1. As its geographical location and climate conditions, Vietnam is usually damaged by typhoons and floods with an annual density of 5 to 10 times per year.

Based on statistics, it found that the annual flood season in Vietnam is usually from June to November, equally 99% of frequency of annual floods. Typhoon density changes and tends to increase. On the distribution of typhoon by region, by monitoring data during 105 years (from 1884 to 1989) shows that major storms occur in the central region (up to 68%), followed by North (30 %) and lightest in the south (2%), (ODA Project document-2010).

1.1.1.3 Geology

About perspective geological structures, Vietnam was divided into five blocks as northeast block, northwest block, Truong Son block, Kontum blocks and south blocks. Geology feature of northern zone differs from southern zone significantly, separated by Kontum a Truong Son blocks.

Northeast and northwest blocks are divided by the Red-River fault. Northern Vietnam has more Paleozoic and Mesozoic formations than southern Vietnam has, and has many faults, with a complicated geological structure. Proterozoic strata are also observed in the northern Red River fault zone. Paleozoic strata are observed only from northern to central Vietnam, all of which are composed mainly of sedimentary rock such as limestone, mudstone, sandstone, and shale.

The oldest geology in Vietnam is Archean Metamorphic rocks in the northwest of the Kontum province in the central part, surrounded by Proterozoic metamorphic rocks. Southern block areas mostly Cenozoic rocks such as sand, silt, clay, clay-silt, clay mixed with gray silt. Hardly any Paleozoic rock distributes in the south of this basement rock. Basalt that erupted in the Neogene and Quaternary era is also distributed in the neighborhood of the western border (Tran, 1995) (JOGMEG - Japan Oil, 2000). Truong Son Block mainly concentrated Mesozoic and Paleozoic such as Ordovician - silurian, carboniferous - premian and clay stone, cretaceous. Kontum block has abundant with Mesozoic and Paleozoic rocks and pre-cambian rock. Geology map of Vietnam is presented in Fig 1.1.

Mesozoic strata are distributed over the whole country as Triassic and Jurassic marine sedimentary and volcano-sedimentary rocks and cretaceous red continental formations. They are composed mainly of limestone, sandstone, siltstone, shale, and conglomerate, and partially coal-bearing deposits known as Hongai flora. Granitic rocks distributed in the whole country include Archean, Proterozoic, Paleozoic, Mesozoic, and Cenozoic.

1.1.2 Landslides and Damages caused by Landslides

High precipitation combined with terrain, complicated geological conditions, especially destroying forested areas causes serious problems related to landslides. As a result, Vietnam is the country has the most serious landslide disasters in Southeast Asia and the Mekong sub-region.

In accordance with ITST's research results, the scientific base for Vietnamese landslide classification is close to the method provided by (Varnes, 1978) Landslides are classified following the types of movements. There are five typical types of landslide including deep landslide, shallow landslide, debris flow, rock fall and topple. As Statistics, the most popular type is shallow landslide, takes 60%. Deep landslides just take about 10-15%, however they are the most difficult and expensive for courter measure. The types above usually occur in rainy season depend on respective condition of terrain, geomorphology, geological structure and hydrology. The percentage of debris flow is around 10% but extremely dangerous. Number of rock falls and topples are small.

Fig. 1.2 Some pictures of landslide taken in transport Vietnam map (Atlas Vietnam)

On the Fig 1.2, a debris flowed on the local road of Sa Pa – Lao Cai Province. B-Rock fell at Nho Que hydroelectric plant 2 (Meo Vac), Ha Giang province with a volume of about 25,000 m^3, made one dead and four missing. C-deep landslide in the local road – Nghe An province made one under constructed bridge stop. D deep landslide interrupted the Highway No. 279 from the town of Pho Rang (Bao Yen, Lao Cai province) to Van Ban district, to Than Uyen district (Lai Chau province). E- Sallow landslide on HCMR – Hue Province. F- Rock fell on the HCMR – Quang Nam province. G- Small gullies with Wedge type occurred on HCMR – Quang Nam Province. H-Sallow landslide appeared on HCMR - Quang Nam province.

According to statistics of the Central Steering Committee for Flood, from 2000 to 2014, it was occurred 250 debris flows and landslides affected residential areas. Landslides caused 646 people dead and missing, nearly 351 people injured; more than 9,700 homes poured away, more than 100,000 homes flooded and damaged, and more than 75,000 hectares of rice and vegetables flooded. The total damage was estimated at over 3,300 billion Vietnamese Dong, equivalent 150 million USD.

Provinces have frequently occurred landslides including mountainous areas of northern zone, central, central highlands and coastal provinces. The landslides concentrate distributing along transport routes with high density.

According to statistics up to 2006 of Ministry of Transport (MOT), total length of highways in Vietnam is about 17,300 km, makes up 6.87% of total length of road network in Vietnam. In which, 3/4 length of highways is on mountainous area and about 30% of those pass through areas with complex geological structures, influenced by the tectonic destruction zone. That is why landslides usually occur every year along transport arteries in Vietnam after rainy seasons, with the annual volume up to millions of cubic meters of soil.

1.1.3 Causes of Landslides

Damage caused by landslides are summarized primarily by objective reasons, such as intense rainfall concentrated in a short period in areas with steep slopes, sensitive geology structural. Beside this, in many cases landslides occurrence have main distributed cause by human economic developing activities that lacks of knowledge of disasters.

Natural environments of Vietnam as the causes of landslides are exacerbated by the fact that Vietnam is a rainy region with tropical monsoon climate. Especially, the high precipitation zone, which covers on mountainous area, distributing on the northwest and the Central of Vietnam could make landslide occurrence seriously. Although Vietnam can be only slightly regarded as an active diastrophic zone, landslides occur frequently in Vietnam. The reasons might include abundance in a sedimentary structure with developed bedding and schistosity as described above, fold structures as a scar of ancient diastrophism, crushing of strata and development of cracks following the fold structures (Tien, D. V. et al., 2016). Therefore, beside characters as natural steep slope, high precipitation, geology took a very importance roll to landslide in Vietnam.

Rapid infrastructure construction, forest cutting down and other customs of agricultural production contribute to increase number of landslide as artificial cause. After the historical flood in 1999 in Middle of Vietnam, landslides occurred on arterial roads caused serious traffic congestion. Vietnamese Government has allowed MOT to conduct difference measures to stabilize of slopes, especially thorough measures with permanent structures to protect and enhance the stability of the slopes along arterial roads impacted by landslides. However, due to limitation of guideline documents and technologies of landslide risk reduction, landslides have fiercely occurred in rainy seasons and continuously caused damages to communities in many parts of the country. Thus, we can say landslide phenomenon is one of the most serious natural disasters in Vietnam, and an urgent matter of Transport sector.

1.2 Abstract of Vietnamese Government's Strategy for Response, Mitigation and Prevention of Natural Landslide Disasters

The Vietnamese government has assessed landslide is one of the considered natural disasters caused major damages to lives and properties of the communities. Decision No. 172/2007/QD-TTg dated on Nov. 16 2007 by the Prime Minister of Vietnam approving the national strategy for natural disaster prevention, response and mitigation to 2020 provides the responsibilities and solutions include:

- Developing science and technologies related to natural disaster prevention, response and mitigation;
- Promoting basic investigation and investment for scientific research and new technology application in disaster prevention, response and mitigation; and
- Modernizing early warning systems from Central, regional to local levels, focusing on efficient communication methods especially for mountainous areas, territorial water and remote areas.

The State encourages the application of advanced scientific and technological achievements to improve capacities of disaster forecast, prediction, warning, and communication; to improve research capacities to observe the Earth's variability and natural changes in the region and territory; encourages the application of advanced technology and new materials for disaster prevention, response and mitigation.

Systematically, scientific sectors have been developed related to disaster: emergencies, disaster management, sustainable development, health care, post-disaster environmental and production recovery.

For natural disaster prevention, response and mitigation responsibilities and solutions for mountainous areas and central highlands, the approach of Government Strategy applied for the areas is to "proactively prevent natural disasters", for which the following solutions are focused to:

- Define and map areas highly prone to flash floods, landslides, geological hazards; make residential planning, evacuate population in dangerous areas, make land use planning, restructure crops, manage mineral exploitation to prevent harmful impacts on the environment and landslide risks, properly plant and exploit forests;
- Establish warning and communication systems down to commune and village levels; build structures to prevent landslides and flash floods; expand flood discharge openings of sluices and bridges on traffic roads to ensure flood drain ability; build reservoir system for both flood and drought control; and
- Strengthen the cooperation with bordering countries in forecasting, warning, search and rescue.

1.3 Research Experiences

Here after, I would like to explain my personal research background for much easy understanding of the thesis extraction.

After graduating Civil Engineering University of Vietnam, I was employed to work as a designer / researcher for traffic construction by Institute of Transport Science and Technology (ITST), belong Vietnamese Ministry of Transport

I had over 8 years of experience in Civil engineering research, feasibility, design and construction supervision and management of large-scale civil and highway projects. During the mentioned time, on the work of design of mountainous road, I larger involved to stability of cutting slope. From this, I was interested in landslide field. Then I send over ten years for research of Landslides.

Therefore, my research experience was established by experiences from civil engineering works and researching in landslide field.

1.3.1 Civil Engineering Works

In the field of civil engineering, I had six reports in Vietnamese language related to road construction materials, structural and experiments. Please refer from List of all study reports (item 1.3.3) from (No.19) to (No. 24). For more concretely, I would like to mention as followings:

For structural construction sector, I studied and developed a guideline regarding design reinforced soil retaining wall for road embankment (Report No. 23) in 2003 and involved subjects maintenance and operation to large-scale technology cable-stayed bridge in Vietnam 2000 (Report No. 24).

For road construction materials, two my technical reports were announced in 2010 regarding to new materials for steel deck pavement includes surface coating of Stone Mastic Asphalt (SMA) and waterproofing of bridge (Report No. 20, No. 22). I studied and developed Vietnamese National Standard of natural gradation for road pavement layers - Specification for Construction, published in 2011 (Report No.19) approved to nationwide application.

In the field of experimental working, I researched and reported research and application of Using Falling Weight Dynamic Project (FWD) for rigid pavement evaluation-2004 (Report No.21). This was one of very useful non-destructive tests in USA for assessment of rigid pavements.

1.3.2 Some Landslide Research References before the Doctoral Dissertation

For landslide research, I have studied and published 18 reports yet. The reports are divided into two parts. The first part includes 14 reports (from Report No.5 to Report No.18) referred as experiences of special landslides before the doctoral dissertation, and 4 reports (from Report No.1 to Report No.4) is used as documents for doctoral dissertation.

The first part of research was results report through two researches project regarding landslide as "Landslide Mitigation Project" - a main joint landslide research project between Ministry of Transport (MOT) and Ministry of Science and Technology (MST) – 2010 and the ODA project "Development of Landslide Risk Assessment Technology along Transport Arteries in Vietnam".

- **Landslide Mitigation Project-main Joint Landslide Research Project between Ministry of Transport (MOT) and Ministry of Science and Technology (MST) – 2010**

After HCMR was opened to national traffic system, there were hundreds of landslide occurred along the road in rainy-stormy seasons, seriously destroyed the roads and made traffic block for several days. The urgent work to research was evaluation the landslide risk and found out how to mitigate this phenomenon. The Ministry of

Transport had assigned me the Landslide Mitigation Project - main joint research project between Ministry of Transport (MOT) and Ministry of Science and Technology (MST) – 2010.

The main outputs of the project included: (1) building up Landslide Basic Data (LBD) of occurred along corridor of HCMR as basic data for research; (2) Creation the method landslide susceptibility base on LBD and causative factors, (3) Making landslide susceptibility map for Thach My- Kham Duc section of HCMR and (4) proposal for countermeasures.

For statistical and survey works of landslide phenomenon, lot of field survey trips were conducted by the research team along the HCMR. There are 548 landslide locations recorded at that time. Each landslide was described and recorded the location from road centerline, the position (relative to pile KM), size and preliminary assessment by the causative factors from the observed landslide signs and characteristics of sliding blocks. In the survey of landslide, causes by lack of the knowledge and experience for study, micro-features were not sufficient care.

Previously, researchers in Vietnam had many views on classification of the phenomena. Landslides were classified to four types as subsidence , erosion collapse, landslides and rock-fall or rock roll (Ho Chat and Tam D. M, 1985); or three types as sliding, flow sliding, fall and rock fall (Ngoc N. S., 2005); or three types as architecture sliding, flexible slip and architecture - flexible slide; or three major landslide categories as falling, landslides, and drifting (Hai D. H and Ho Chat, 2002). The classifications provided by Vietnamese authors agreed with Varnes' method (Varnes, 1978), which depended on the types of sliding movement and material sliding blocks. Landslides occurring along the HCMR can be divided into four categories as the sallow landslide (55%), deep landslides (32%), erosion and flow type landslide (12%) and rock fall (1%). The above classification is still controversial.

Causative factors affecting landslides were also studied and analyzed. There are many reasons given, focusing on four basic groups: geomorphology-topography, geology, climate and human impacts. In the group, the causes were analyzed and 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. rainfall) usually targets of the study. The important factors were selected for the evaluation of the sensitivity of the phenomenon. Depending on the availability of the data, the factors were considered, including slope angle, weathering, geomorphology, fault density, geology, drainage distance, elevation, precipitation and land usage.

The assessment of sensitivity map was conducted by experts with evaluated views using AHP algorithm. Landslide susceptibility was divided into low, medium, high and very high sensitive classes depending on the evaluation weight. However, the evaluation weights differ by no unified opinion from evaluators. However, as the result, it had 67% of landslide in high and very high area of sensitive classification map.

Along with the results of this research project, three research results (Report No. 16, No.17 and No.18) were published in Vietnamese language. They are landslide classification along HCMR-Proceedings of Symposium ITST 2012; Landslide Susceptibility map for HCMR (Thach My – Kham Duc Section) - Proceedings of Symposium ITST 2011; and Method of mapping the areas of landslide along Ho Chi Minh highway-Vietnam transport Journal, Jan and Feb 2012 (ISSN: 0866-7012).

- **The Project ''Development of Landslide Risk Assessment Technology along Transport Arteries in Vietnam''**

Under the efforts to forecast and mitigate the impacts of landslides, an ODA project has been suggested. The proposal idea of cooperation between Japanese and Vietnamese researchers regarding the landslide risk assessment was discussed. The report No.15 for landslide situation in Vietnam and cooperation with the International Consortium on Landslides in enhancement of research and treatment for landslides on road network has submitted and presented in the 10th Anniversary of ICL – January 2012, Kyoto.

After this project had been approved with the support from the Japanese Government, report No.14 presented the project scientific framework. The project's purpose is to develop landslide risk assessment technology in order to reduce landslide disasters along main transport arteries and on residential areas, train and develop human capacity for the effective use of this technology. The report was submitted and presented at the IPL Symposium, UNESCO, Paris, 2012.The expected project outputs include: (1) preparation of integrated guidelines for the application of developed landslide risk assessment technology and capacity development by WG1-Joint Team of all groups; (2) wide-area landslide mapping and identification of landslide risk area by WG2 - Mapping Group; (3) development of landslide risk assessment technology based on soil testing and computer simulation by WG 3 - Testing Group; and (4) risk evaluation and development of early warning system based on landslide monitoring by

WG4 - Monitoring Group.

As the WG2 activities in the mentioned project, Reports No. 13 and Report No.10 were submitted and accepted for Proceedings of the SATREPS Workshop on Landslides in Vietnam in July 2014 by ICL (ISBN: 978-4-9903382-2). Respectively, they regard to the Objective Function based AHP Risk Evaluation System in Humid Tropical Regions and the Change of safety factors by the series of land deformation at a typical landslide along the National Road No. 6, Vietnam.

Report No.11 of new technologies for Landslide Risk assessment was an approved paper for the Journal of Science and Technology of Vietnam published by the Ministry of Science and Technology in 2014 (ISBN 1859-4794). This article refers to a number of new technologies for risk assessment, which is being development for the generally management as well as in case solutions, in order to minimize the loss of landslide phenomena. Technology used to establish forms of landslide maps with different functions are applied to disaster risk management for the regions on a large scale. The in-room technologies as soil testing and computer simulation, small scale simulation for wireless extensometer in multi-depth monitoring for surface displacement of slopes under artificial rain, landslide monitoring and early warning of landslides are applied for the concrete positions, areas especially for large-scale and high risk landslide cases.

Report No.10 concerning the detection of active landslide zone from aerial photograph interpretation and field survey in central provinces of Vietnam was submitted and accepted in Proceedings of World Landslide Forum 3, 2-6 June 2014, Beijing.

Three reports No.7, 8 and 9 were submitted and presented at the Landslide conference hold by Japanese Landslide Association in 2015. They respectively concentrate on the topographic and geological features of landslides in Vietnam, a trial of risk evaluation based on wide landslide topographic mapping in Vietnam and development of landslide risks assessment technology along transport arteries in Vietnam.

Then, two reports No. 6 and No. 5 respectively named as “Outline, typology and the causes of Landslides in Vietnam” and “The current manual and standards for the survey and design works for Landslide prevention in Vietnam” were carried on causes of landslides, limitations in concept of Landslide evaluation and giving out countermeasures. The reports are presented in the special issue of Transactions, Geomorphological Union vol.37-1 in January, 2016.

1.3.3 List of all Study Reports

1. Tien D. V. (1) Toyohiko Miyagi (2), Shinro Abe (3), Eisaku Hamasaki (4), Hiroyuki YOSHIMATSU (5) - Landslide susceptibility mapping along the HCMR in the Central of Vietnam - an application of an AHP approach to humid tropical area - Transactions, Japanese Geomorphological Union, vol.37-1; January, 2016;
2. Tien D. V. (1), Hiroyuki Yoshimatsu (2), Kazunari Hayahi (3), Toyohiko Miyagi (5), - A prediction of Landslide Classification by pattern recognition of fuzzy inference method along the HCMR in central zone of Vietnam - Transactions, Japanese Geomorphological Union, vol.37-1; January, 2016;
3. Tien D. V. (1), Shinro Abe (2), Hiroyuki YOSHIMATSU (3), Toyohiko Miyagi (4),- Geological mechanisms of landslide generation along HCMR in the Central of Vietnam -Journal of Japan Landslide Society - Vol .52, No4 (226) July 2015;
4. Tien D. V.(1), Toyohiko Miyagi(2), Eisaku Hamasaki (3), Shinro Abe(4), Nguyen Xuan Khang (5)- Landslide prevention and mitigation for road in humid tropical region - The 4th volume of World Landslide Forum 3 (WLF3) -2-6 June 2014, Beijing;
5. Ngo Doan Dung (1), Tien D. V. (2), Nguyen Xuan Khang (3) - The current manual and standards for the survey and design works for Landslide prevention in Vietnam - Transactions, Japanese Geomorphological Union, vol.37-1; January, 2016;
6. Tien D. V. (1) Shinro Abe (2) Ngo Doan Dung (1) Do Ngoc Ha (1) Toyohiko Miyagi (3)-Outline, typology and the causes of Landslides in Vietnam - Transactions, Japanese Geomorphological Union, vol.37-1; January, 2016;
7. Ngo Doan Dung (1), Tien D. V. (2), Shinro Abe (3), Do Ngoc Trung (4), Toyohiko Miyagi (5)-Topographical and Geological feature of Landslide in Vietnam-2015-Abstracts of the 54nd annual meeting of the Japan landslide Society-(2.5);
8. Toyohiko Miyagi (1), Shinro Abe(2), Eisaku Hamasaki(3), H.Daimaru (4), T.Shibasaki (5) , K.Hayashi (6) , Tien D. V. (7), Le Hong Luong (8), Ngo Doan Dung (9) - Current Study of the Landslide Risk Evaluation in Deep Weathering Region-A Trial of Risk Evaluation base on wide Landslide Topography Mapping in Vietnam – 2015 - Abstracts of the 54nd annual meeting of the Japan landslide Society-(2.4);
9. Kyoji Sassa (1), Hirotaka Ochiai (2), Toyohiko Miyagi (3), Tien D. V. (4) Nguyen Xuan Khang (5), Development of Landslide Risk Assessment Technology along Transport Arteries in Vietnam –2015- Abstracts of the 54thannual meeting of the Japan

landslide Society-(2.3);

10. Le Hong Luong (1), Toyohiko Miyagi (2), Shinro Abe (3), Eisaku Hamasaki(4), Tien D. V. (5), Detection of active landslide zone from aerial photograph interpretation and field survey in central provinces of Vietnam - Proceedings of World Landslide Forum 3, 2-6 June 2014, Beijing;

11. Tien D. V. (1), Xuan Khang Nguyen (2) Kyoji Sassa (3) Eisaku Hamasaki (4), Toyohiko Miyagi (5), Shinro Abe (6), - New technology in Landslide Risk assessment - Journal of Science and Technology of Vietnam - Ministry of Science and Technology-2014 (ISSN 1859-4794) (*);

12. Ngo Doan Dung (1), Eisaku Hamasaki (2), Tatsuya Shibasaki (3), Toyohiko Miyagi(4), Hiromu Daimaru (5), Tien D. V. (6), Le Hong Luong (7), Change the safety factors by the series of land deformation at a typical landslide along the National Road No.6, Vietnam - Proceedings of the SATREPS Workshop on Landslides in Vietnam, 2014; (ISBN:978-4-9903382-2-0)

13. Eisaku Hamasaki (1), Toyohiko Miyagi (2), Tien D. V. (3), Ngo Doan Dung (4) - Objective Function based AHP Risk Evaluation System in Humid Tropical Regions - Proceedings of the SATREPS Workshop on Landslides in Vietnam, 2014 (ISBN:978-4-9903382-2-0)

14. Tien D. V. - Technical Cooperation Project to Develop Landslide Risk Assessment Technology along Transport Arteries in Vietnam - Proceedings of the IPL Symposium, UNESCO, Paris, 2012;

15. Minh Tam Doan (1), Tien D. V. (2) - Landslide situation in Vietnam and Cooperation with the International Consortium on Landslides in enhancement of research and treatment for landslides on road network - Proceedings of the 10th Anniversary of ICL – January 2012, Kyoto;

16. Tien D. V. – Landslide classification along HCMR – Proceedings of Symposium ITST 2012 (*);

17. Tien D. V. - Landslide Susceptibility map for HCMR (Nghe An - Thach My - Kham Duc Section) - Proceedings of Symposium ITST 2011 (*);

18. Tien D. V. – Method of mapping the areas of landslide along Ho Chi Minh highway-Vietnam transport Journal, Jan+Feb 2012 (ISSN: 0866-7012)(*)

19. Tien D. V. - Vietnamese National standard (TCVN) - Natural Gradation Using for Road Pavement layer – Specification for Construction. A Vietnamese National Standard, Code TCVN 8858-2011.- Research Project Director (*);

20. Bui ngoc Hung (1), Tien D. V. (2) - Research Project on waterproof materials to preserve the steel bridge deck (2010) research project of Ministry of Transport (MOT) (*);
21. Tien D. V. - Research and application Project of Using Falling weight Dynamic (FWD) for evaluation rigid pavement -2004 (*);
22. Bui Ngoc Hung (1), Tien D. V. (2) - Research and application Project of Stone Mastic Asphalt (SMA) to rehabilitation of surface pavement on the steel bridge deck (2004). Research project of Ministry of Transport (MOT)(*);
23. Tien D. V. - Design guideline on soil reinforced retaining wall for road embankment. ITST research project (2003). Research Director (*);
24. Pham Van He (1), Tien D. V. (2) - Research project on the maintenance and operation technology to large - scale cable-stayed bridge in Viet Nam. Research project of Ministry of Transport (MOT) 2000 - Research member team (*).

Note: (*) The publications were written in Vietnamese.

1.4 The research Issues

1.4.1 Vulnerability of Landslide Hazard

Landslides are a natural phenomenon directly concerning to topography and slope formation processes. These processes are the result of a comprehensive combination of climatic and crustal movement and taking place in very long time. However, looking at a slightly shorter scale, topography is essentially formed through a combination of rock strength, weathering processes, and erosion stress (Eisaku H. and Toyohiko M.i, 2012).

To a natural slope, the stage of its existence depends on internal impact and external factors. Internal factors may change by outside action as weathering, metamorphosis, organization or other geology and morphology phenomenon. External factors such as the rain, earthquake, and stream impact contribute to the increased strain and decreased shearing strength. As the result, balance stage is broken and landslides process is created. Unstable slopes process may have the cause by two factors in the same time or each individual one.

Vulnerability of landslide hazard is portability of slopes by landslides. Slope portability includes the slide of original slope (the slope that in its history creation process got erosion only) and the slope has occurred landslide in the past. For occurred landslide slopes, this continuous moving of exiting landslide is considered as re-active landslide. So when discuss to vulnerability of landslide hazard we will mention to two scientific concepts. Those are the landslide risk assessment to re-active landslides and the Landslide susceptibility to slope. The issues that I studied concerning to vulnerability of landslide hazard are discussed as following.

1.4.2 Landslide Prevention and Mitigation for Roads in Humid Tropical Region (The 4 th Volume of World Landslide Forum 3 - WLF3)

Report No. 4

The landslide phenomenon is considered as a natural disaster directly affected the development of mountainous areas in general to the traffic and transportation sector particularly. From the damages of typical landslides in Vietnam such as on highway No. 37 (at Chen Pass), Son La province; Nam Non bridge on the Western route, Nghe An province; at Hai Van Pass station; on highway No. 6; and along the HCMR in the Central, it is able to be recognized that the responding in face to this dangerous phenomenon seems to be quite passive.

This paper proposed a new strategy proactively to prevent and mitigate the occurrence of this natural disaster for the new design and management of roads through mountainous terrain areas.

The new strategy core is to build up a vulnerability of landslide integrated tool map (LITM) by the combination of landslide risk assessment map (LRAM) and the landslide susceptibility map (LSM). While LRAM is developed from landslide inventory map, LSM is analyzed from landslide manifestation in study area and landslide causative factors such as topography, geomorphology, geology, climate and human impact as a basis for predicting the future.

For LRAM and LSM, methods of analytical hierarchical process approach or fuzzy relation may be applied. This proposed map indicates boundary, active status of each landslide as well as the susceptibility of each coordination to landslide that is fully effective for landslide prevention and mitigation of hilly and mountainous areas with humid tropical climate, including Vietnam.

1.4.3 A Prediction of Landslide Classification by Pattern recognition of Fuzzy Inference Method along the HCMR in the Central of Vietnam

(Transactions, Geomorphological Union vol.37-1 in January. 2016.)

Report No. 3

From 2012 to 2014, multi Landslide investigations have been taken a long HCMR in order to collect as many as occurred landslides for assessment. The occurred landslides were classified according to Varnes Classification. However, because of the complication of phenomena and depending on point of observatory some landslide cases had a non-consensus in classification. Therefore, a study of Landslide Classification by pattern recognition of fuzzy inference method along the HCMR is proposed for study. For landslide mitigation, a degree of risk valuation and the construction of prevention measures are necessary to prevent this landslide disaster. Therefore, it is necessary to execute a pattern recognition of different type classification. Cause of landslide having a various moving style, but the analysis of this type classification is affected by the various factors we examine this analysis method of Landslide Classification in consideration of fuzzy nature. We show that the weathering of the ground, a geological features and landslide scale are important factors through this analysis. The propose method is high technique analysis precision and could be applied for Similar Assessment Application

1.4.4 Geological Mechanisms of Landslide Generation along HCMR in the Central of Vietnam (Journal of Japan Landslide Society-Vol 52, No4-226. 2015)

Report No.2

In the Central of Vietnam, HCMR runs from south to north along the border with Laos. In this area, HCMR is often closed due to numerous landslides during the rainy season. Thus, there is an urgent need to determine the generation mechanism of landslides and to conduct risk assessment.

For this purpose, the area was chosen as one of the study areas for this project. This study focuses on landslides occurring at approximately 180 locations along the 150 km distance (linear distance) from Thanh My (west of Da Nang city) and the intersection with National route 9 (west of Quang tri). The landslides are classified based on the type of movement in order to determine the triggering mechanism. The survey was conducted from 2012 to 2014.

The type of landslide movement in this area differs significantly depending on whether if the area is Paleozoic metamorphic zone or Mesozoic sedimentary zone. The type of landslide movement in this area differs significantly depending on whether if the area is Paleozoic metamorphic zone or Mesozoic sedimentary zone. In metamorphic area, weak aspect such as schistosity, beddings, faults, and joints associated with geological structures become shear planes. Translational slides (wedge type) and rotational slide/flow (gulley type) occurs often in this area, with the infiltration of surface water and breaking of rocks by weathering as the cause. On the other hand, in Mesozoic sedimentary area, translational rockslides are most common, where coal layers disrupted by fold structures function as the slip surface.

It was shown that these landslides are not simply caused by heavy rain and weathering typical of the tropics, but are closely associated with geology, geological structure, development of rivers, and cuesta topography. This result shall be an important indicator in future study of Vulnerability of Landslide Hazard.

1.4.5 Landslide Susceptibility Mapping along the HCMR in the Central of Vietnam - an Application of an AHP Approach to Humid Tropical Area. (Transactions, Geomorphological Union vol.37-1 in January. 2016.)

Report No.1

Landslide is considered as one of the dangerous phenomenon that often occurs in the mountainous region of Vietnam and directly affects to the lives of the people in the region, destroys the traffic infrastructure the road system. This paper introduces an overview of the natural conditions of the studied area locates along the corridor of the HCMR, in the provinces of Quang Tri and Thua Thien-Hue, Quang Nam in order to focus on the spatial analysis of landslide susceptibility in this area. There are various possible causes for land sliding with complex inter–relationships. However, in practice a detailed assessment to find the main causes of each landslide is not feasible in most cases. The selection of causative factor for landslide susceptibility map is usually base on expert's subjective experience. In this study, to analyze landslide manifestation, causative factors are derived of slope anger, type of rock, fault density, distance to the road, land used and precipitation. Maps for causative factors were created, in which each one was divided in to classes.

From position of 604 slope failures appeared along the HCMR a landslide distribution was build up. The sensitiveness to landslide of each classical zone of causative factor maps is calculated and then evaluated thought the value of number occurred landslide - NOL and density of occurred landslide DOL. These values were the result of comparison of landslide distribution map and each causative factor maps using GIS application.

An analytical hierarchical process is used to combine these maps for landslide susceptibility mapping. As the result, A landslide susceptibility zonation map with 4 landslide susceptibility classes, i.e. low, moderate, high and very high susceptibility for land sliding, is derived based on the inventory map of observed landslide from 2006-2009. This map indicates that 82.66% total number of occurred landslide, which have been reported fall into highly and very highly susceptible zone.

Even there was limited matter concerning relevant, scale and available data, the landslide susceptibility map of this study for corridor along this road is credible for landslide mitigation.

1.5 Strategy of Report Establishment

1.5.1 Research Objectives and Subjects

In Vietnam, mountainous terrain accounts for up to 3/4 of all territory. The country is situated on a dangerous cleavage terrain affected by the Earth crust's powerful tectonics. Bordered by the Pacific Ocean, it is also influenced by the monsoon climate, with high average annual rainfall, and complex geological structures with jagged geomorphology. Landslides are the most important "natural hazard", especially in northern and central Vietnam.

Research objectives are to develop a comprehensive method to assess the vulnerability of landslide hazard of slopes for tropical regions. It should be conducted a study for a significant landslide classification method, analyses of the relationship between landslide phenomena with causative factors, creating a landslide susceptibility map then developing a guideline for vulnerability of landslide hazard. The research will contribute to forecast, prevent and mitigate the negative impact of the landslide phenomenon for planning, land use, construction of infrastructure, ensuring the safety of existing traffic roads and mountainous residential areas in Vietnam. The research results can be applied for areas with similar conditions.

Fig. 1.3 Location of the study area

The study subject is a zone including HCMR corridors in the the Central of Vietnam, where the landslides are regarded as frequent and dangerous phenomena causing widespread economic damage to the transport sector and local residents. The strategic route of HCM is nearly 1800 km long from Hoa Lac (Hanoi) to HCM City. This route is a part of the North–South expressway master plan approved by the Vietnamese government. The target of the study section is approximately 300 km of HCMR, which begins from the junction with national Highway No. 9 (at the cable stay Bridge Dakrong- Quang Tri Province) to Dong Loc, Dak Glei Kontum Province. In this research, the study area is a zone limited by a distance of 20 km offset to both sides from the center-line of HCMR, extending northwest and southeast between the latitudes of 16° 40'N and 15° 30'N and longitudes of 106° 15'E and 106° 50'E; extends to three provinces of Quang Binh, Hue, and Quang Nam. The study area is presented in Fig.1.3.

1.5.2 Research Methodology

The research methodology is applied as under flowchart in Fig.1.4. The principle for building the chart is based on “for the landslides, the past and the present are the key to the future" (Vaners, 1984). By this one, occurred landslides will be recognized as many as possible, depending on the capacity of recognition in order to build up a landslide basic data. (Because landslides are processes by the time and, the human capacity recognition is limited and in some cases together with other topography and slope formation processes, the cover of vegetation in tropical forest could delete their signals for recognition).

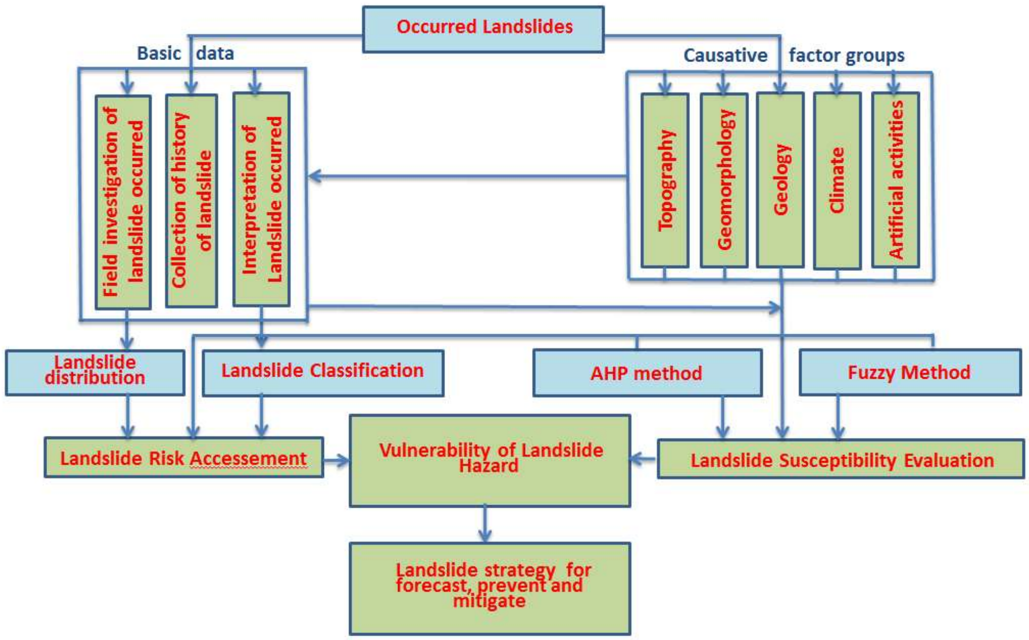

Fig. 1.4 Flow chart for Vulnerability of Landslide Hazard Research

For landslide basic data, three basic methods commonly for inventory maps were employed. They are field recognizance to investigate landslide occurrences, collection of historic information of landslide and interpretation of landslide occurrences from aerial photographs. From investigated landslides, the relationship between causative factors such as topography, geomorphology, geology, climate and artificial activities and landslide distribution, micro topography will be studied. Rules regarding landslide distribution could be obtained for landslide classification, risk assessment and landslide susceptibility.

For landslide classification, conventional one is based on landslide characters regard with material and movement type. A new approaching classification bases on it and additional relation with regarding factor such as weathering of the ground, a geological features and landslide scale is considered. Fuzzy nature method can be applied for this classification.

Landslide risk assessment is the comparison of the sensitiveness to re-activate slide among investigated landslides. Landslide micro topography is the interior of the landslide body, head, side, and toe. To each landslide, the internal micro topography of landslide bodies including compacted hill, flow traces/flow hills, sub scarp, detached scarp/fissured depression is very useful information for understand landslide processes history. Fig.1.5 presents Landslide micro topography (A) for Period of landslide maturation (bedrock) and (B) for Period of landslide occurrence on weathered rock - colluvial soil. The information form basic data concerning to position, micro features and causative factors are very important for assessment. For comparison and evaluation, methods of analytical hierarchical process approach or fuzzy relation are applied. Depend on the value of assessment; the sensitiveness to reactive could be divided in groups of low, moderate of high classes.

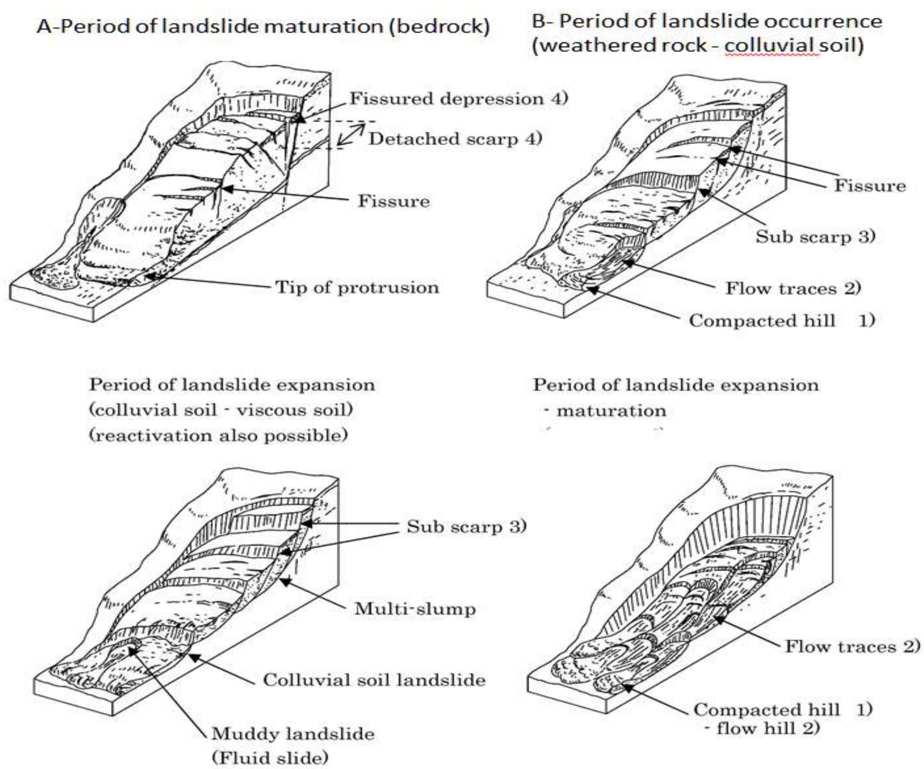

Fig. 1.5 Landslide micro topography (Eisaku H. and Toyohiko M.i, 2012)

To assess landslide susceptibility, the identification of causative factors, which are classifiable 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) usually targets of the study. Actually, the landslide process depends on many causative factors such as topography and geomorphology, geology, climate, and human impact. However, depending on concrete study zone, the relevance, availability and scale of map (Slide, R. C. and Ochiai, H., 2006) necessary factors should be used. Therefore, as objects of analysis for this research, minor and indirect factors were ignored. We concentrated in direct factors 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 map, in which each factor map of the study area was classified into many different classes groups. The weight of each factor will be considered by results of analysis relation between occurred landslides with each classes factor map using GIS. Methods of analytical hierarchical process approach or fuzzy relation are applied for evaluation the weight contribution of each factor then overlay causative maps with calculation weighs are carried out. As the results, 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 for forecast, prevent and mitigation for a region.

To assess vulnerability of landslide hazard, the landslide risk assessment map (LRAM) and landslide susceptibility map (LSM) will be the effective tools for forecast, prevention and mitigation the negative impact of the landslide phenomenon for planning, land use, construction of infrastructure.

1.5.3 Main contents of research

Title of research: Vulnerability of Landslide Hazard in Tropical Region

Abstract

Preface

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Central of Vietnam

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Chapter 7 Conclusions and Recommendations

References

CHAPTER 2 –LANDSLIDE PREVENTION AND MITIGATION FOR ROADS IN HUMID TROPICAL REGIONS (Tien D. V. et al., 2014)

2.1 Vietnam's Natural Features Relating to Landslides

Vietnam is located on the Indochina Peninsula in Southeast Asia, with the population of about 90 million people and the terrain changes as natural Zones. The topography of Vietnam is varied depending on the natural areas. Overall, Vietnam is composed of three geographic domain extends from North to South. In which, the North has mountainous terrain concentrated in the Northwest and the Northeast, plus the Red River Delta; the Central has a strip of coastal plain and high mountains called Truong Son mountain range adjoins Laos; and the South's major terrain is the Mekong Delta.

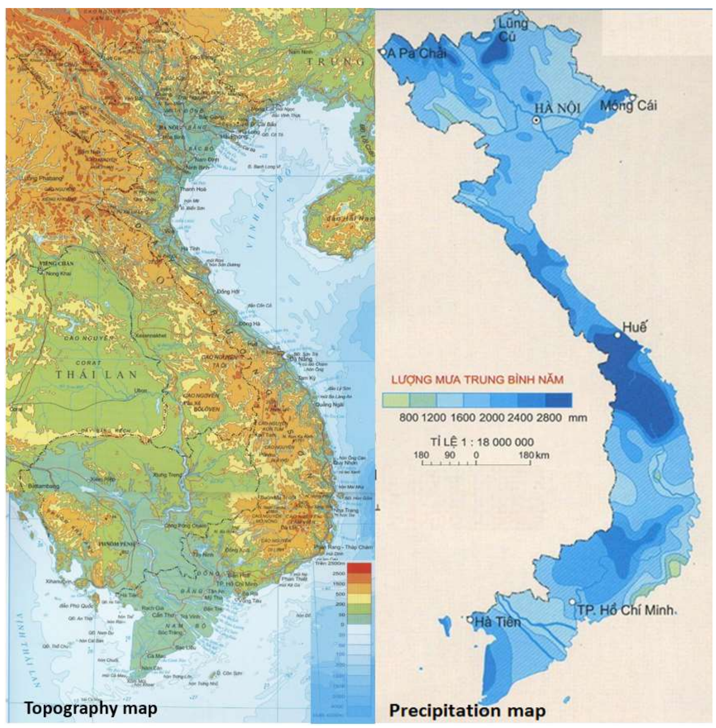


Fig. 2.1 Terrain and rainfall distribution map of Vietnam (Atlas Vietnam)

The average annual rainfall throughout the country is from 1,200 to 3,000 mm and can reach to 4.000-4500 mm/year in some particular areas in the Central. The average sunshine duration is 1,500 and 3,000 hours/year and the average temperature fluctuate from 5°C to 37°C. Particularly, sometimes the temperature drops to 0° C (at Sa-Pa) or increases to 40-45 ° C (for instant, in Hanoi, Ha Tinh, Quang Binh). Vietnam usually has to deal with typhoons and floods every year, with an average of 7 to 10 typhoons/ year. Terrain and rainfall distribution map of Vietnam are presented in Fig 2.1.

In such natural conditions, landslide is one of the most popular natural phenomena occurring on road network in rainy season in Vietnam, while it is located in extreme climate areas where are impacted by heavy rain, high terrain, strong cleavage and complex geological structure.

2.2 Landslides Damaged the Transport System in Vietnam

To get an overview of landslide activities, we collected information and analysed data of some large typical landslides occurred on Highway No. 37 (at Chen Pass), Son La Province, The Nam Non Bridge on the Western Route, Nghe An Province, at Hai Van Pass Station, on Highway No. 6 and along the HCMR in the Central.

2.2.1 Chen Pass Landslide Case

National Highway No.37 connects Red Star Town, Hai Duong Province to Cu Nui intersection, Mun Village, Hua Nhan Commune, Bac Yen District, Son La Province in Vietnam. The landslide occurred at km 447 +500 -: - Km 448 +100 of National Highway No.37 is considered as sallow slide but large scale with of the width of 650 meters and the height of 950m in size, on the concave slope which bounded by two water lines converge. The average slope was 20 degrees with the strong cleavage surface.

This zone has a complex structural stratigraphy. Clay coating is golden brown chips with many debris, multi-mineral rolling rocks. The state changes from hard to soft. The cover is weathered, has strong ability to absorb water. That is the targets of cohesion and friction angle decreased when being hydrated. The original rock beneath is ultra-mafic rock in grey-green, dark grey and light grey colors, derived from magma eruption and shallow intrusion and beneath is the crystalline schist sandwiched with grey limestone particles.

The movement of the slope was triggered by the combination causes of the mechanical properties deterioration of soil and rock, which was water permeable and saturated due to heavy rain and the cut slope when upgraded and renovated national Highway No.37 in 2003 at the foot of landslide block. Overview of Chen Pass landslide zone is presented in Fig 2.2. Main scrap on the landslide is presented in Fig2.3.The movement of mass destructed partially Highway No.37 at two positions and formed four scraps on slopes with a height from 5-19m.

Fig. 2.2 Overview of Chen Pass landslide zone

Fig. 2.3 Boring activity for geology investigation on landslide body where main scrap was determined.

The countermeasures using geotechnical technology or structure to terminate the movement of the landslide were too complicated and not financially feasibility. A bypass project nearby has been launched, however with the same conditions of topography, geology and hydrology the bypass are still capable to meet similar risk.

2.2.2 Landslides along National Highway No.6 Hoa Binh province

National Highway No.6 is one of the arterial roads connecting Hanoi to Hoa Binh, Son La, Dien Bien and the other northern provinces of Vietnam with a total length of 504 kilometers. Along the particular section from Km 78 +300 to Km 158 through Hoa Binh city, Cao Phong, Tan Lac and Mai Chau districts, the slope failure phenomena of artificial cut slope, falling down to the pavement often appears threaten traffic safety and cause traffic jam. The landslide distribution map of Hoa Binh province area and National Highway No.6 is presented in Fig 2.4.

Only in the scale of Hoa Binh Province, there are about 30 observed landslide zones in which 12 locations have high frequently failures as partly rapid slope landslides. These locations were evaluated and assigned as very high sensitive points in the countermeasure plan. The sensitivity was assessed on the basic of comparison of some factors affect the stability of the cutting slope such as slope angle, digging height of roof, appear of cracks, natural geological formations and history of tectonic activities. These activities were considered as cause create new faults that disrupted the geology structure and changed characters of metamorphic and crumpled fractured sedimentary rock, improved water infiltration, reduced shear capacity of rocks in the region.

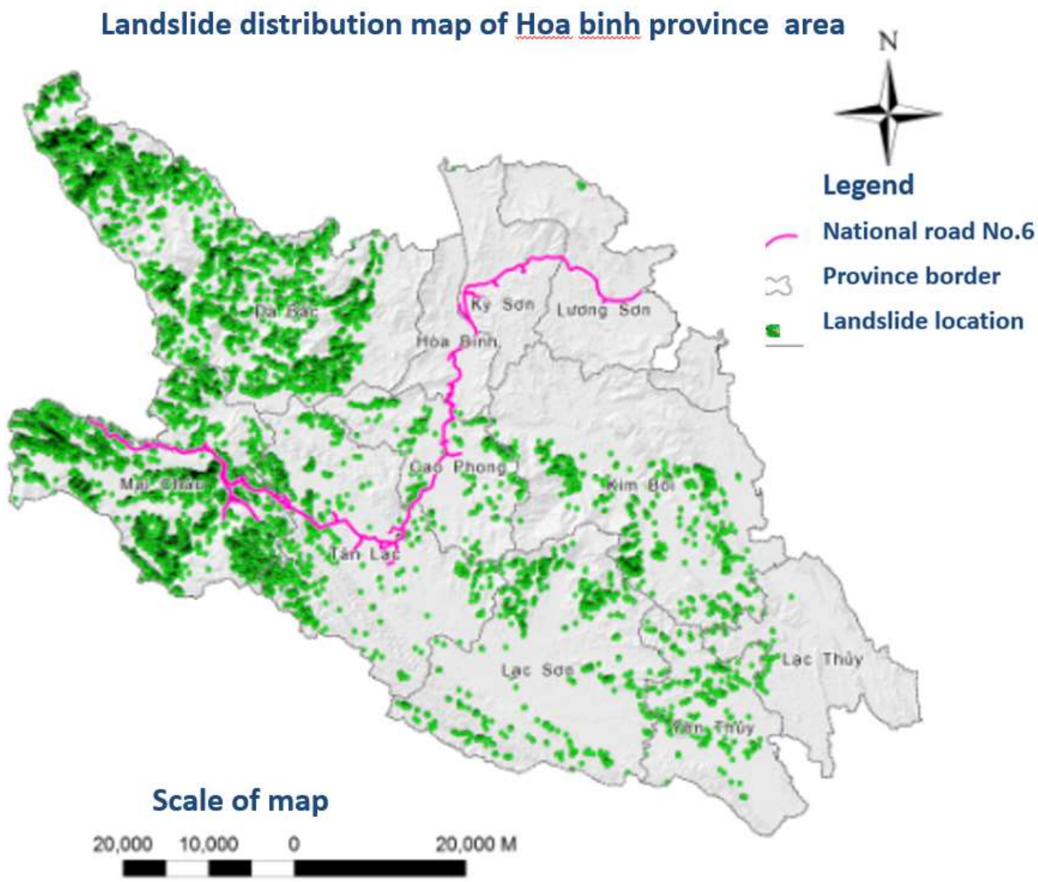


Fig. 2.4 The landslide distribution map of Hoa Binh Province area

Most serious one was rapid slope failures of 150,000 m^3 of debris from the artificial slope which was passive occurred on 2012 Jan 16 at Km 138 +750, located in Dong Bang commune, Mai Chau district, killing two people and causing congestion traffic for several days. Another most recent rapid slope failure of more than 20.000 m^3 of soil and rock on 2013 Feb 22 (in dry season) at Km 138 +800, causing traffic jams for hours. Thankfully, this landslide did not damage the lives and property of the people.Fig 2.5 presented the mentioned landslide location just after occurrence.

Sensitive assessment of moving slopes is a complex issue depending on many factors, which need to be analyzed based on a combination of scientific analysis and expert opinion. The identification and assessment of risk positions in a number of cases can be recognized through signal of movement such as partly slides moving or cracks appearing on the slopes through site survey or by analyzing of some particularly sensitive parameters such as geological structure, slope characteristics, height of slope. However, it did not provide an accurately and qualitatively comparative evaluation. Some slopes belong to high-risk and very high-risk group of landslide even there are no signs of movement cannot be found. In case of landslides along National Highway No.6, Hoa Binh Province. Most positions are selected based on landslide occurred as partly rapid slope failures.

Fig. 2.5   The rapid slope failure at Km 138 +750, Dong Bang Commune, Mai Chau District, Hoa Binh Province

2.2.3 Landslide at Nam Non Bridge

The Nam Non Bridge is an importance technical key of road West Nghe An, My Ly commune, Ky Son district, Nghe An province. The bridge was designed as pretreated concrete structure crossing the lake of Ban Ve hydropower plant. In June of 2011, Ban Ve hydropower plant began content the water.

The water level in the lake rose up from elevation from +185 to +200 m. The abutment which was located on the down slope of mountain beside and deep in resin up water elevation, was detected a movement of 30 cm horizontally and 40 cm vertically. Overview of landslide is presented in Fig 2.6

The survey for the cause of movement was conducted and exposed that this abutment located on form landslide, which was re-active under the influence of heavy rain, rising up the water level of lake and the activity of cutting natural surface slope for temporary construction road.

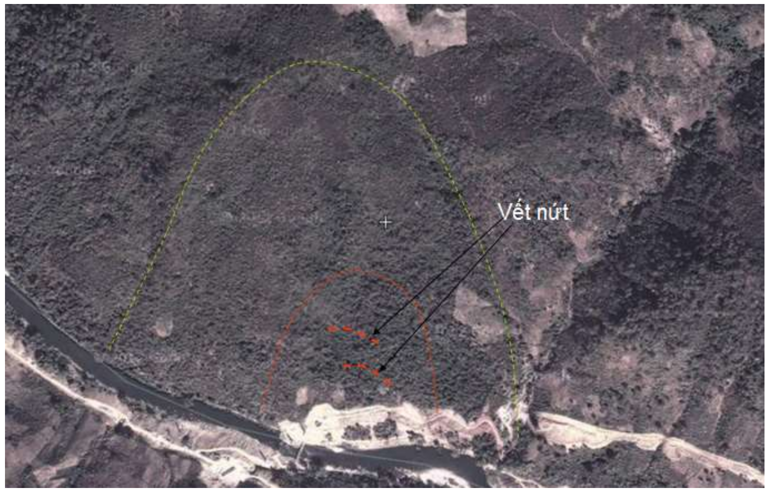


Fig. 2.6 Landslide at Nam Non Bridge, West Nghe An road, My Ly commune, Ky Son district, Nghe An province (google map)

This landslide size was 950 m in width and 1,150 m in height. A sliding block with size of 400 m in width and 500 m in height showed the significant sign of movement and made three deep cracks from 18 m to 20 m. Longitudinal profile of moving massive presented in Fig 2.7.

Geological investigation combined with geophysical survey results shows that geological profile including five layers.

Layer 1 is Pebble grit, which only distributed in the river area.

Layer 2 is yellow brown clay soil, hard plastic state with 1.2 to 2.2 m thickness.

Layer 3 (3A) is strong weathered siltstone with TCR = 20-30%, RQD = 0, 9.5 m thickness;

Layer 4 is strong to moderate weathered siltstone; TCR = 55-60%, RQD = 20-30%, 20.6 m -34.2 m thickness, and

Layer 5 is Sandstone in blue gray, light gray, dark green color, slightly weathered, little cracks, greater than 5m thickness. The slip surface is predicted at the bottom of layer 4.

Both the provided plans for landslide countermeasure to meet the requirement of safety operation and long-term use of the road and the bridge that are handled to stop movement of the landslide and finding a new place for reconstruction of bridge are not economic and engineering feasibility. Exploiting temporary solution and non-continuous monitoring are employed to ensure traffic for the time being.

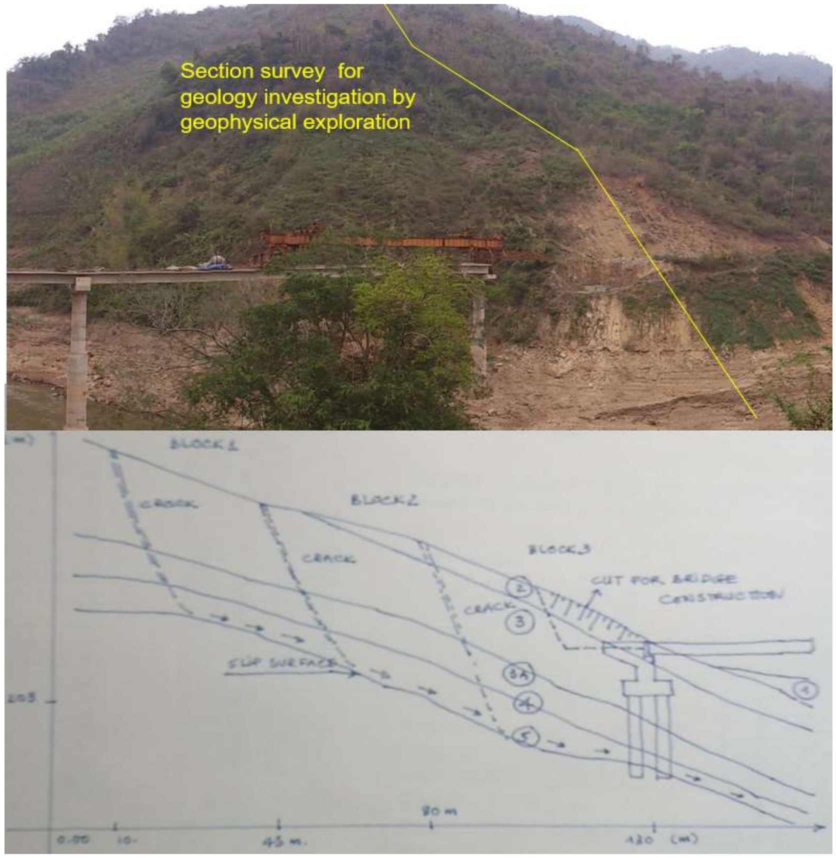


Fig. 2.7 Draft of Longitudinal geology cross section of moving mass by geophysical exploration method.

2.2.4 Hai Van Station Pass Landslide Case

Hai Van Pass station is a particularly important position on the north-south railway line in the central region. Located on the lower position of the peck of Bach Ma Mountain, overlooking the beach where has special geological structure with unconsolidated soil mixed with block granite rocks, yearly this position accepted a very large rainfall (over 3000 mm / year). There are over 30 trains pass through this station per day. This landslide phenomenon is the greatest threat to the lives of passengers using trains when passing through this area in the rainy season. The landslide and topography map in Model Acad 3D is presented in Fig 2.8.

This landslide position was strengthened by concrete frame and retain wall and put in operation in 2004 Dec 31. Then less than four months from operation and have not "facing" with the rainy season, this construction work was serious damage. Overview of the landslides at Hai Van Pass stations presented in Fig 2.9.

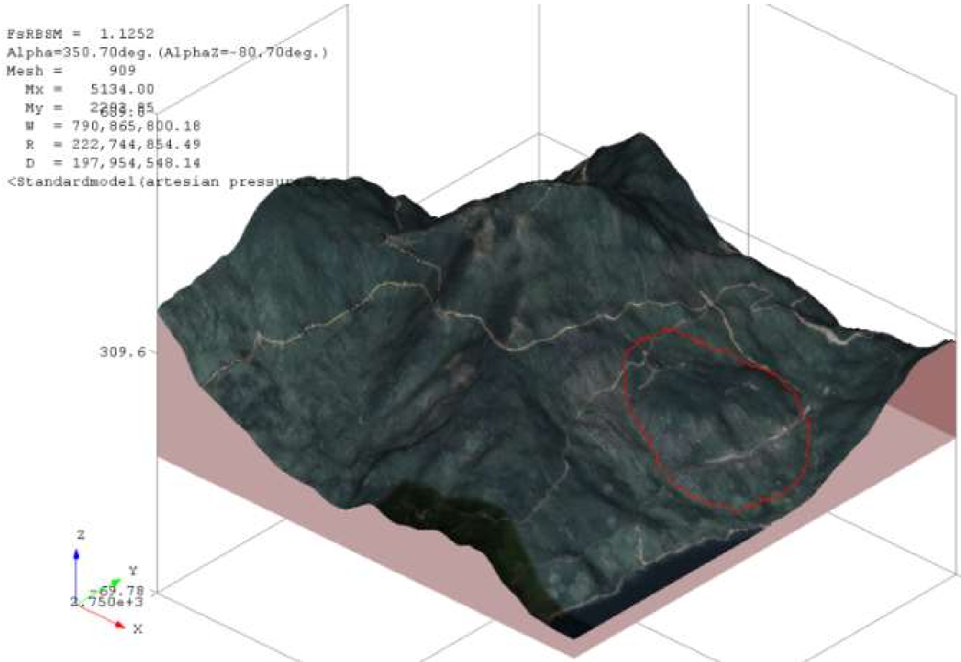


Fig. 2.8 Model Acad 3D of Hai Van Pass Station

Fig. 2.9 Location landslides at Hai Van Pass station (photo by Doan Minh Tam)

A ten-square-meter block of soil in slope mountain collapsed. Construction materials, concrete patches, steel bars for landslide strengthening had broken and rushed. Many "orphaned" rocks loose leg or rolled down, located in the middle of slopes wondrously. Railway line and station located right at the foot of this mountain was a serious threat.

The cause of the damage seems related to unsuitable strengthening solution that was not yet fully appreciate the classification and scale of landslide.

2.2.5 Landslides along the HCMR via Vietnam Central

HCMR from Pac Bo to Dat Mui is nearly 3200 km long. The whole route is divided into 3 segments. (The Pac Bo - Hoa Lac; Hoa Lac-The Binh Phuoc intersection, Chon Thanh - Dat Mui). HCMR section via Vietnam Central is one in the second segment and considered as one of the best damage section influenced by of the landslide phenomenon.

After the traffic operation, since 2006, along the HCMR in the Central, many landslides have occurred. According to the statistical data before 2012, in the study zone 472 slope failures appeared with different size. There were eight particularly sections along the HCMR with high landslide risks, potentially frequent in rainy seasons, including Da Deo - Khe Gat Pass , the Northern of U Pass, Khu Dang Pass, Cong Troi Pass, Sa Mu Pass, Hai Ham Pass, Song Bung Pass and Lo Xo Pass.

Fig. 2.10 Illustrates typical landslides often occur in HCMR –Vietnam (Minh Tam.D and Tien D.V, 2012)

According to survey data, the most of slope failures were cut-slope of road, which was collapsed under directly impact of rain. Types of movement could divide them into three main categories, slides (32.1 %), fall and topper (55.9%) and flow

(11.9%).Illustrates typical landslides often occur in HCMR –Vietnam is presented in Fig 2.10.

The studding record of survey could show that most landslide phenomenon had character of sallow landslide, largely related to raining fall, the surface of the terrain that was strong weathering and the direction of geological slope layer had the same direction with cutting slope of the road. Slip surface usually appeared at the position of interface geological or different weathering layers.

In those cases, Slip surface usually had non-large radius and toe of surface of rupture usually ended up at middle or end of the cutting slope of the road embankment. Accumulation of landslide was soil or debris and greatly influenced by surface water and ground water, moved following stream over the road surface.

However, a small member of slip surface with a large radius was predicted as old landslides, located under the road embankment. The sliding movement of the deflection and accumulation zone of deep landslide created cracks and in some cases putted pavement or facilities of road over and they is continues to move with slow velocity depending on the water absorption of the sliding block. Fig.2.11 presents the Illustration of landslides on the HCMR.

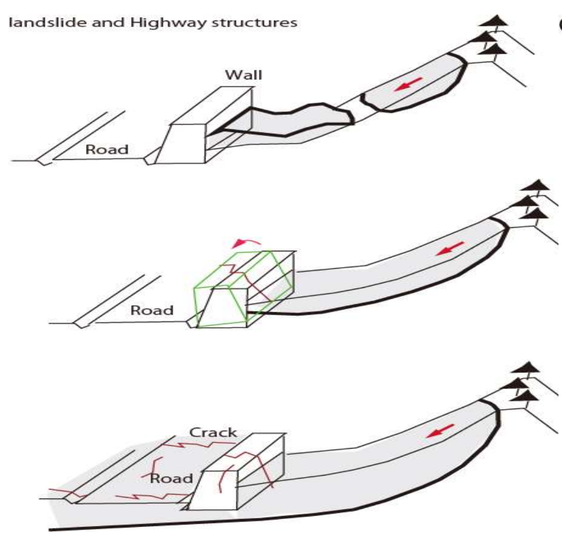


Fig. 2.11 Illustration of landslides on the HCMR (Abe report,2012)

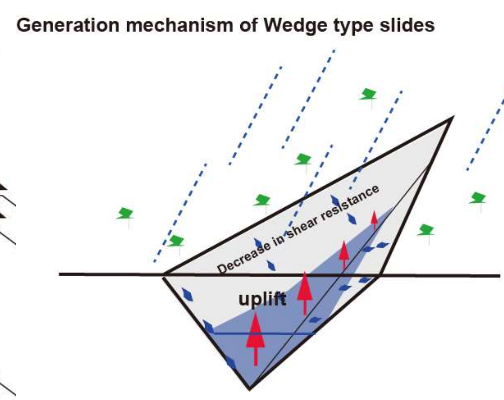


Fig. 2.12 Mechanism of flow related to the geology character of surface (Abe –Satrep proceeding report 2014)

The most of cut-slope failures on the HCMR had classification characteristics close with the fall and topple causing by unsuitable cutting slope design and non-

protection slope from water penetration through cracking and strong weathering texture of the surface layers, which was removed vegetation, and surfacing cut off partly.
The movement could be recognized firstly from the upper step or middle steps of the cutting slopes, after that combined with other phenomena such as erosion (Rock falls was found in some cases but the number of this phenomenon is small). Because of this phenomenon, the remaining slopes were more steps and in some cases nearly vertical created high potential energy for slope failure to continue development.

At most those locations, the direction of geological slope layer, which was strong weathering, was reverse with cutting slope surface of the road. Depending on the material of surface, movement here of all most slope failures were Earth fall/topple, debris fall/ topple. Material after slope failure occurred was unconsolidated soil, debris and water.

Flow was phenomenon, which observed pretty on the research area directly related to the geological characteristics of the surface and the phenomenon of surface water flow. Mechanism of flow related to the geology character of surface is presented in Fig 2.12. The development of the small gullies is the initial manifestation of the phenomenon due to the movement of soil particles or fragments of withering surface, which had special characters as Wedge type following surface water.

The small gullies developed larger and created deep gullies on the surface of slopes, and in some cases, they likened together and as the result the slopes failure by the cause of this phenomenon others type of landslide such as slide or fall.

2.3 Current Situation of Survey, Design and Management of Mountainous Roads

2.3.1 Survey and Design for New Mountainous Roads

The objectives of traditional survey and design of mountain roads are proposed a reasonable and shortest route between the interested points. The road proposed alignments are firstly considered base on the original topographic maps with different scales. Based on road alignments from topographic maps, alternatives are studied by carrying out site topographical surveys, site geological and hydrological investigation. Depending on the important degree of the road function, the road survey and design are divided into basic-design phase, engineering-design phase and construction drawing design phase. Finally selected alternatives for investment largely bases on feasible road alignments of basis design step.

The feasible selected alignment is often determined by considerations of economic indicators and synthesis techniques such as appropriation to the terrain, meet requirement of traffic engineering and transportation, lowest construction costs and minimal fee for maintenance of road alternatives. In Vietnam, the road survey and design comply with the standard 22 TCN 263-2000 (for survey of motorways) and standards TCVN 4054-2005 (for road design). For the effects of natural phenomena such as landslide, the standard 22 TCN 171-87 (process engineering geological survey and design for countermeasures to stabilize embankment of road in the landslide activity area) was issued and updated recently to national standard TCVN 9861-2013. However, the instructions for selection of road alignment to prevent and mitigate landslide phenomena from those standards are significantly general and mainly focused on only countermeasures in case landslide occurred.

The important information that the designer need to decide the direction of road alignment to prevent and mitigation landslide areas are where is high landslide sensitivity zone and occurred landslides. To active landslides, type classification, landslide location, boundary and dimensions (including width, height and depth) as well as the moving stage of landslides should be recognized. To a target area including occurred landslides, the risk evaluation to each one should be considered. Fig 2.13 is presented as an example for illustration of the design highways Ban-Etsu, Japan that was designed to avoid sensitive landslides. By the conventional survey methods, especially in areas with mountainous terrain covered with dense vegetation, the identifying information of occurred landslides is very difficult. In addition, the movement of the slope is a complex issue with many affecting factors related to topography, geomorphology, geology, climate and hydrology as well as the impact of the people, so to evaluate the sensitivity of each position requires in-depth knowledge of experts. It is the fact that for survey and design of mountain roads, Vietnamese design engineers still lack off the tool for consideration of landslide prevention and mitigation.

Failure to recognize the important information related to landslide phenomenon as well as non-assessing the sensitivity of them leads to the selection of road alignments going through high sensitive areas, even though the body of large - scale landslide blocks. With only small effects of excavation of natural slope or other adverse factors, the movement will continue to slide with different speeds. Rapid failure slopes caused by heavy rain are one of typical landslide encountered along the mountain roads.

Many new road sections in Vietnam, soon after operating, in adverse conditions such as heavy and extended rains, landslides occurred in large numbers with different scales has stopped traffic, causing damage for the lives and property of the community. To some roads during the construction process, these drawbacks had revealed when project road alignment was chosen at the positions, where active large-scale landslide located that conventional survey process did not detect out. In such cases, the change of this road alignment will lead to huge costs of investment for changing road alignment or for landslide countermeasure to stop movement. Beside this, in nearby area, making a landslide bypass may face to similar risk.

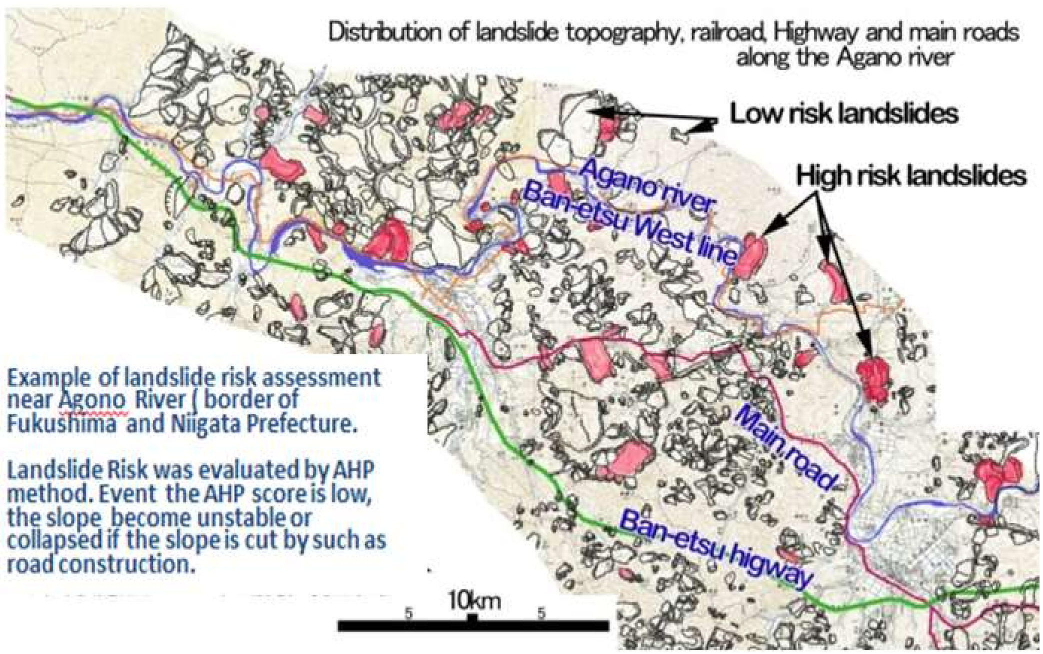


Fig. 2.13 Illustration of the design highways Ban-Etsu, Japan which was designed to avoid sensitive landslides (Miyagi,2014)

2.3.2 Management and Exploitation of Mountainous Roads

Duty of road manager is to keep the road in good condition for traffic, in which road slope maintenance is an important target, especially to mountain roads. For slope maintenance, the works include inventory of cutting slopes along the road, prediction the slope failure susceptibility and doing routine maintenance. To do the good job, road manager need to tools for mitigation such as landslide susceptibility map, the prediction the stable factors of high susceptibility slope sections for creation of maintenance plan. In fact, the most of mountainous road have no landslide susceptibility map. To some one, even landslide susceptibility map have been developed, however, the scale of them is quite large and only suitable for general study. The unit managers of highway through mountainous areas will require detailed landslide susceptibility maps. Because lack off detail one, the road slope was not classified into sections with graded landslide susceptibility for sufficient works of strengthening and maintenance. Therefore, during the rainy season, landslides are kicking phenomenon occurring frequently and were passive to management unit.

To slope failures occurred along the road, the inventory and risk assessment of them are necessary for making plan for mitigation. However, because of lack off the knowledge regarding evaluation of relative so landslide risk assessment had not been done. So plan for landslide mitigation usually not accuracy and passive.

For landslide countermeasure, effectiveness of alternative is decided by well understanding of designer regarding type of movement, micro feature regarding to stage of landslide, prediction the stable calculation factor of each condition. The most of those was not considered sufficient so that many landslide giving out was not effective and failure, especially countermeasure for large scale one.

So for landslide prevention and mitigation to management and exploitation of mountain roads especially during the rainy seasons of every year, the landslide mitigation tools is subjected as following:

(1) Knowledge training regarding to landslide classification, topography of landslide micro feature regarding to causative factors such as geology, topography, morphology, climate and artificial cause.

(2) Development Intergraded landslide maps such as landslide inventory, susceptibility, risk assessment as well as hazard map.

(3) Guideline for landslide mitigation including landslide countermeasures depending on each landslide classification and condition.

Therefore, to proactively deal with these landslide phenomena for new designing and management of road, a new strategy should be considered.

2.4 Propose a New Strategy Proactively to Prevent and Mitigate Landslide

For landslide disaster prevention, response and mitigation, it is necessary to have a tool, which supports for management. The ideal of development a landslide risk assessment, which can predict possibility of movement of occurred landslides, is response and mitigation requirements. Creation of landslide susceptibility map for predicting the potential of slope movement is prevention requirement.

The new strategy core is to build up a vulnerability of landslide integrated tool map (LITM) by the combination of landslide risk assessment map (LRAM) and the landslide susceptibility map (LSM). While LRAM is developed from landslide inventory map, LSM is analyzed from landslide manifestation in study area and landslide causative factors such as topography, geomorphology, geology, climate and human impact as a basis for predicting the future.

2.4.1 Objectives and Principles of LITM

The fact is that if we depend on landslide risk assessment or susceptibility only, the landslide prevention and mitigation is not effective and insufficient. For an example with a slope, which was evaluated as low landslide susceptibility, but the unstable slopes still occurred because it may contend an old landslide, which now is re-active. The overall objective is to find a method to proactively deal with the phenomenon of landslides by creating a tool to answer these basic questions. They are where is landslide occurred, what is the current moving status, and which is the area with higher landslide risk possibility in comparison with other neighboring regions.

For the transport sector, the construction standards to prevent and minimize damage from landslide for the design, construction and maintenance of transportation projects should be built base on the risk assessment map and susceptibility map, which is defined here after as landslide integrated tool map (LITM). This LITM is a combination of the landslide assessment map and the landslide susceptibility map. In the landslide assessment map, the landslide areas are identified and all necessary information such as landslide classification coordinates, size, boundary, movement status and the sensitiveness to reactive stage will be showed. The landslide susceptibility map is built based on the analysis of landslide causative factors through their relationship rule of them to occurred landslide before.

Although there are some conflicting views among the experts, however, research on methods to LITM are based on agreement as following, (General scheme for LITM is shown in Fig. 2.14.):

1) The main condition causing landslides can identify, and most can be shown on the map. There are many causative factor concerning to landslide and usually is divided in to four groups as topo-morphology, geology, climate and artificial actions. However, 10 factors usually directly relate to landslides slope anger, weathering, land

used, geomorphology, fault density, drainage distance, elevation, precipitation and human actions. To each landslide, the weight of distribution to the landslide may difference. The main cause trigger landslide can identify. Landslide position, boundary and micro feature can be realized mostly through aerial photographs through stereoscopic projection, or based on field surveys (Varnes, 1978), (Hansen, A., 1984)

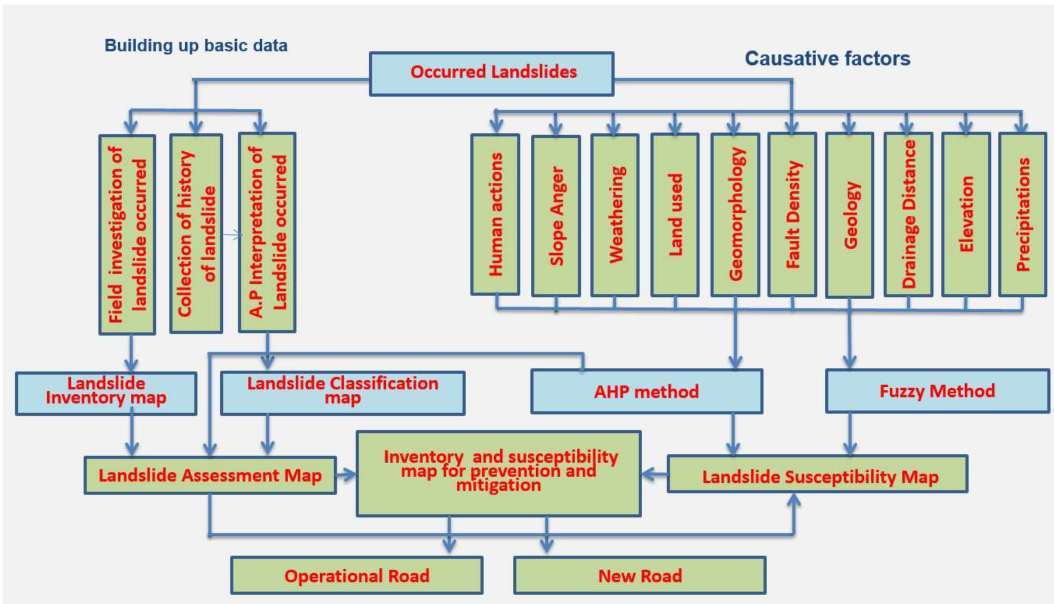


Fig. 2.14 General scheme for LITM

2) For the landslides, "the past and the present are the key to the future" (Vaners, 1984). Landslide is a changing processes the morphology by the time, which was impacted by many other natural morphology, geology and climate. In another hand, the human capacity of landslide recognition is limited. So for approaching to the natural rule of landslide occurred landslides will be recognized as many as possible. For a region, landslides in the future may occur in the same geological conditions, geomorphology and hydrogeology as it happened before. From recognized landslides, landslide rule concerning to relative factors is study for understanding then landslide prediction could be made. Therefore, to understand clearly about the movement of landslide in the past is very importance to assess landslide causes.

3) A region is at risk of taking classes sorted by different probabilities. In ideal condition, landslide risk should be considered by all causative factors. Classes sorted by different probabilities can be gathered and used to build predictive models landslides by landslides phenomena controlled by the laws of mechanics, by which we can

determine empirically, probability statistical. However, depending on relevant, available and scale of data map, limited causative factors may be used for evaluation. From occurred landslide data, there are many method for evaluation such as AHP or fuzzy or their combination. If there is only use one or a combination of inadequate access above, risk assessments typically landslide accuracy or confidence level lower.

2.4.2 Landslide Risk Assessment Map

The first step to development a landslide risk assessment map is creation of the landslide inventory map. It is considered as the basic data for landslide risk assessment map that is built based on the landslide distribution and classification maps. With objective of information providing such as type, location, boundary and size, including width, height and depth as well as the moving of landslide, this kind of maps with smaller ratio of 1: 25000 will be very useful for the design of new roads and management of the existing roads.

Commonly three basic methods of inventory maps were employed: field recognizance, collection of historic information and interpretation of landslide occurrences from aerial photographs. (Long N. T., 2012). Landslide classification would be done base on landslide interpretation combine with landslide investigation method.

With the development of theory geomorphology and technology interpretation aerial photographs, the landslides and their process can be identified and explanation. Air-photo interpretation could be done with one or better multi aerial phase taken. The interpretation of aerial photographs over time combined with topographic maps can give us many useful information including land use, landform and vegetation classification, landslide terrain deformation, landslide distribution characteristics of the landslide displacement (Toyohiko M., 2012). The detailed analysis of smaller scale aerial photographs can make more detailed landslide topography map showing the internal characteristics of landslide, and create the ability to predict the next movement of sliding block. This is significant for the study and offer solutions to stop or mitigate for the specific landslide case, especially large-scale one. In case there is only a period of aerial photo is provided, the landslide movement can be determined additionally through the moving signs during field survey. Through field surveys combined with the knowledge of the geology and geomorphology, landslide characteristics such as main body, main scarp, head, crown, cracks, of landslide could be determined. Block diagram of idealized of landslide is presented in Fig 2.15.

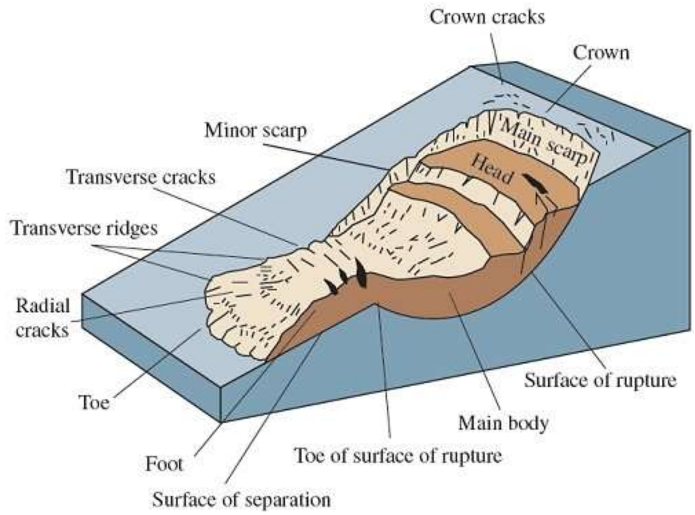


Fig. 2.15 Block diagram of idealized of a landslide (U.S. Geological Survey, July 2004)

To field investigation, signs of displacement of landslide can be realized through landslide micro features and the change of vegetation cover. The movement as well as its direction of soil masses can be analyzed from the appearance of stress on surface slope (tension, compression and shear stress) (Abe, S., 2013). Therefore, besides getting the basic information of landslide from air photo interpretation, field recognizance is necessary for clear and detailed characters of landslide.

A question giving out to landslide inventory map is the comparison of the sensitiveness to reactive stage among investigated landslides. From micro topography, the sensitiveness to reactivate will be evaluated. During this process, causative factors such as topography, geomorphology and climate, etc. will be considered combining with landslide micro topography for evaluation. For evaluation, the methods of analysis and evaluation by analytic hierarchy process (AHP) may be applied. As the results, a landslide risk assessment map could be created, in which the sensitiveness to re-active will be classified in classes as low, middle, high and very high. This kind of map will be contribute for prediction of risk evaluation of Landslide Hazard Vulnerability.

2.4.3 Landslide Susceptibility Map

In general, the landslide susceptibility map usually consists of three main processes: (1) landslides situation analysis and associated cause factors, (2) Develop a database and (3) model selection, calculation methods and creating landslide susceptibility map.

Basic contents of landslides situation analysis and causative factors is creating inventory map. The basic parameters such as type, location, boundary and size, including width, height and depth as well as the moving status of the landslide are the basis for analyzing the relationship between the landslide mechanism and the factors influence to the process in study area. All mentioned information should be recorded and present to a landslide distribution map. The preliminary assessment of relevance between the current state of the distribution of landslides and the factors that be related as terrain slope, rainfall, land cover, geology, geomorphology, crust, or fault lineament density ... can be based on the analysis, superposition of maps in GIS and field investigation.

Develop a database is preparation next step. Beside inventory map, causative factors affecting landslides process in the study area, is shown by the creation the component map of causative factors. Theoretically, there are many factors affecting the movement of landslide, which contains the elements of direct and indirect factors. In general, causative factor groups include: (1) topography, geomorphology, (2) geology, (3) climate, and (4) impacts. The element factors of causative groups will be assessed, classified and selected to provide sensitivity ones to the landslide phenomenon. Normally, sensitivity factors influencing the landslide are usually mentioned as the slope angle, weathering, geomorphology, fault density, geology, drainage distance, elevation, precipitation, land using. However, depending on specific conditions and experts' discussion and evaluation about the important levels of each factor as well as the availability of data sources, the creation of this map is different. Important requirement of component maps of causative factors affecting the landslide process in the study area is the scale of map. This map must have the same scale same with the susceptibility map that we want to have.

Two mathematic methods usually are employed for susceptibility map, that are methods of analytical hierarchical process approach (AHP) which is based on weighted influencing assessment factors of experts or fuzzy relation which is based on comparison affected parameters of the occurred landslides and parameters of position that we want to predicted. Based on the selected mathematic methods, GIS software is often used to create the susceptibility map through the overlapping causative component maps in the same geographic coordinates. The weight of causative factor is considered and evaluated based on character of landslide distribution in study area regarding to causative factors. The landslide susceptibility zonation map with four landslide susceptibility classes, i.e. low, moderate, high, and very high susceptibility for land sliding, is derived based on the correspondence with an inventory of observed landslides.

2.4.4 Creation of LITM

The finally process of Creation of LITM is showing information of inventory map and susceptibility map in the same geographic coordinates. The basic information parameters of LITM include classification, location, boundary and size, moving status, and susceptibility to the occurred landslides as well as prediction of landslide susceptibility class for the zone that landslide has not happen yet.

2.5 Conclusions

Due to the unique natural conditions, as discussed above, the landslide is one of the natural phenomenon usually occurs seriously in severe arterial roads passing through mountainous regions of Vietnam in the rainy season. By analyzing the effect of landslide to specific locations and arterial road it can be recognized that strategy to deal with natural phenomena previously for the design and management of construction in order to prevent mining the roads in mountainous area and mitigation is passive and low efficiency.

The use of LITM as presented above with the current survey methodology will useful for the designer in choosing the optimal road alignment that satisfies the economic and technical requirements. Selected road alignment prefers to avoid active landslides, high-risk assessment landslides and high susceptibility landslide zone. In case selected alignment cannot prevent mentioned zone, the designers have to actively provide proactive and minimize solutions response. For existing roads, LITM will be useful in the landslide classification, sensitive assessment of each position and support for hazard map in case landslide occurred, giving early warning system to ensure the safety of lives and property and actively giving out countermeasures for high susceptibility position before landslide takes place.

A new proposed plan as mentioned is giving out, which bases on creation of LIMIT to go well with the current standard will be effective for both economic and technical aspect, contributes to reducing the damage of landslide phenomena arising due to climate change to traffic systems particularly and the development of infrastructure in general. It also considered as new strategy for landslide disaster prevention, response and mitigation of other fields of Vietnam national economic.

CHAPTER 3 – LANDSLIDE CLASSIFICATION BY PATTERN RECOGNITION USING FUZZY INTERENCE METHOD ALONG HCMR IN THE CENTRAL OF VIETNAM (Tien, D. V. et al., 2016)

3.1 Introduction

The HCMR along the border with Laos in the Central of Vietnam often suffers traffic stoppage because of frequent landslides that occur during the rainy season. These landslide disasters, which are important geological hazard phenomena, have caused damage to many lives and socioeconomic activities in the areas concerned. To prevent these disasters, studies are in progress to produce susceptibility mapping based on GIS to predict sites presenting risks of a landslide disaster (Yalcin, 2008); (Pradhan, et al., 2010). However, the landslide phenomena is intricately related to meteorological conditions, such as physiographic factors, geological factors, and heavy rain. For that reason, movement types are classified as falls, topples, slides, spreads, and flows (Varnes, 1978), (Hunger, O. et al., 2014).

Moreover, the motion speed and on-site inspection approach of a moving block differ according to this landslide type (Fell, R. et al., 2000). No preparation methodology for susceptibility mapping that includes factors related to these various movement types has been proposed to date. Particularly, movement types are affected by the geotechnical conditions prevailing at a real site. The degree of risk assessment and proposed construction method countermeasures differ depending on a slope crustal block's movement type. Risk judgment according to each movement type therefore it enables to construct the higher-precision occurred landslide risk assessment map. It also allows to apply an economical survey technique and effective planning of a countermeasure construction method. Therefore, it is necessary to find highly accurate classification procedures used for the types of landslide phenomena.

For prediction of the landslide sensitiveness, it requires evaluation of its risk. This risk evaluation involves to geological, physiographic, and weather factors, including many attribute factors that include ambiguity because of linguistic expression. Analysis by fuzzy modeling is useful for the evaluation of slope stability using these ambiguous factors by linguistic expressions. It is extremely important to introduce a membership function that expresses ambiguity for the application of fuzzy theory.

The related researches include: fuzzy theory application using Mamdani method (Demicco, R.V. and Klir,G.J., 2004); a triangular membership function according to experts' opinion for evaluation of slope stability (Saboya, F. et al., 2006); fuzzy theory application that introduces experts' empirical knowledge into implementation of recognition of the classification patterns of bedrock (Aydin, 2004); comparison between fuzzy theory and the AHP method introducing the frequency distribution of the attribute factors of a landslide as a fuzzy membership function (Pourghasemi, H.R. et al., 2012); susceptibility mapping using a membership function by the cosine amplitude of the correlation coefficient between a landslide and its attribute factor parameters (Ercanoglu, M. and Gokceoglu, C., 2004); (Kumanan, S. et al., 2008); evaluation of the occurrence of a landslide disaster caused by an earthquake using a sigmoid and linear membership functions to evaluate ambiguity based on experts' knowledge (Champatiray, P.K. et al., 2007); analytical study of susceptibility of a landslide by the fuzzy operation of the fuzzy product, fuzzy sum, and fuzzy Gamma of the fuzzy set of an occurrence frequency ratio acquired from factor analysis using input-output (Pradhan, 2010); prediction of a landslide hazard area by introducing a membership function from the ratio of occurrence frequency distribution of landslide factors, and the grand total of each factor to determine the susceptibility index of a landslide from the fuzzy operation of fuzzy product, fuzzy sum, and fuzzy gamma (Bui, D.T. et al., 2012a) and (Bui, D.T. et al., 2012b) ; and study of the setting method of a membership function using the occurrence frequency ratio of landslide attribute factors proposed by (Lee, S. and Talib,J.A., 2005) (Aksoy, B. and Ercanoglu, M., 2012). An approach is usually employed for setting a membership function for modeling of the fuzzy theory concerns the correlation between cosine amplitude and occurrence frequency.

In the field of classification problems, fuzzy classification methods have been proposed based on the fuzzy if--then rule that can accommodate ambiguous data as a problem that determines the class of a given sample from its attribute factor, i.e., a pattern recognition problem (Nozaki, K.et al., 1994). This approach has a characteristic by which it can carry out nonlinear classification with no complicated expression by expressing inference rules using fuzzy if-then rules as linguistic knowledge. What matters in this case is the acquisition means of fuzzy if-then rules. They are acquired as experts' knowledge or by the frequency distribution analysis of the occurrence factor of a landslide (Ercanoglu,M. and Gokceoglu,C., 2002); (Aydin, 2004); (Saboya, F. et al., 2006); (Wang, W.D et al., 2002); (Pradhan, 2010); (Bui, D.T. et al., 2012a).

A procedure for generating fuzzy if--then rules automatically from numerical data has also proposed recently (Pradhan, B., 2013) A fuzzy if--then rule is a fuzzy theory process that formulates nonlinear susceptibility mapping between input and output data (Kumanan, S. et al., 2008). This method (ANFIS: Adaptive Neuro Fuzzy Inference System) comprises the following:(1) selection of fuzzy rules as a rule base,(2) setting of a membership function used for fuzzy inference as a database, and(3) inferential analysis to input factors given as an inference mechanism. It successively updates the weighting factor of connection of inference by the maximum grade method so that the least squares error between an input factor and output inference is minimized (Oh,Hyun and Pradhan,B., 2011); (Bui, D.T. et al., 2012b); (Cabalar, A.F. et al. , 2012). This examination provides fuzzy if-then rules that are necessary for the execution of inference. Studies using an artificial neural network are also conducted (Vhahidnia, M.H.et al. , 2010) as an approach for the analysis of nonlinear relation between input attribute factors and the susceptibility of a landslide using the fuzzy inference of Mamdani.

However, conventional fuzzy inference has generally employed a radial basis function and a triangular function for a membership function. Because they are not a trapezoidal membership function, expression of the ambiguity of an input factor is restricted to a narrow width. In addition, an approach to analyze the weighting factor of an output layer exists by a genetic algorithm using a trapezoidal membership function (Theresa, M.M.J. and Raj, V.J. , 2013). Nevertheless, it does not optimize a membership function corresponding to input attribute factors and output inference. Several analytic methods using attribute factors with ambiguity corresponding to the movement type of a landslide has been proposed for the classification problem of landslide types. This study accordingly investigates a fuzzy type classification procedure using genetic algorithm for consideration of the geotechnical ambiguity of attribute factors.

3.2 Landslide Classification by Fuzzy Theory

3.2.1 Landslide Classification by Fuzzy If-Then Rules

The following fuzzy if--then rules are used in the case of a pattern recognition problem with two input variables:

Rule R_{ij}^{k}: If x_1 is A_i^k and x_2 is A_j^k then

(x_1, x_2) is Class C_{ij}^{k} with $CF_{ij}^{k} = 0.9$ (1)

Therein, CFijk is the confidence value of a fuzzy if--then rule. This fuzzy if--then rule signifies that the pattern class of a sample is "Cijk" and its confidence value is 0.9, where its attribute factors x1 and x2 are "Aik" and "Ajk", respectively. Because this method is specially expressed with a pattern recognition rule by linguistic knowledge, conclusion obtained is easier for the public to understand.

Generation of these fuzzy if-then rules requires the following conditions: (1) fuzzy partition of a pattern recognition space, and (2) identification of fuzzy if-then rules.

This analysis adopts non-uniform triangulation but trapezoidal fuzzy partition by Nozaki et al. (1994), which allows more ambiguity expression. Fig 3.1 presents an analysis case that consists of attribute factors of two types as this simplest pattern recognition problem.

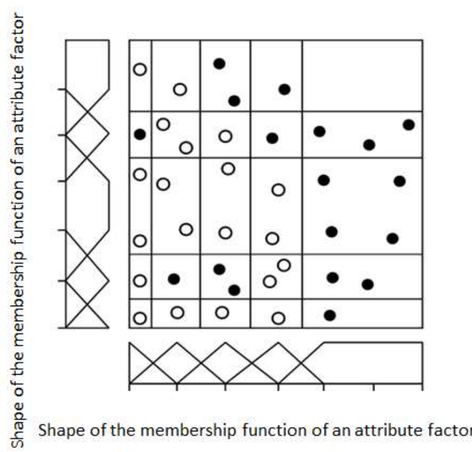


Fig. 3.1 Fuzzy partition with fuzzy trapezoidal grid

Because a fuzzy partition of these attribute factors is implemented in an arbitrary classification by a trapezoidal membership function, the partition divisions are fewer than fuzzy partitions by uniform triangulation. This implementation reduces the number of fuzzy if-then rules, thereby improving the efficiency of classification computation and reducing dummy rules for unidentifiable regions. Consequently, this implementation is expected to generalize classification ability and improve precision in the type classification of diverse landslides.

Investigating all the executable partition solutions on the partition of a fuzzy classification space is not a realistic approach, but it is a necessary approach to obtain the optimal solution by searching some part thereof. For that reason, this study adopts genetic algorithms (Nozaki, K.et al., 1994).

The conclusion C_{ij}^k and confidence value CF_{ij}^k of a fuzzy if-then rule are computed using the following procedure

. (1) Generation of fuzzy if-then rules

A fuzzy if--then rule is identified by computing the grand total of compatibility β_{ct} corresponding to the fuzzy subspace of a given pattern class $A_i^k \times A_j^k$ by the following equation.

$$\beta_{ct} = \sum_{p \in ct} \mu_i^k(x_{p1}) \cdot \mu_j^k(x_{p2}) \qquad (2)$$

In that equation,

β_{ct} Grand total of compatibility

$\mu_i^k(x_{p1})$ is the value of a trapezoidal membership function of A_i^k of rule k,

p is the serial number of attribute factors, and

ct denotes the pattern class.

(2) Computation of the pattern class group CX that maximizes β_{cx}

Next, the pattern class group CX that maximizes β_{cx} determined using the equation above is computed with the following equation.

$$\beta_{CX} = \max(\beta_{C1}, \beta_{C2}, \cdots \beta_{CM}) \qquad (3)$$

When multiple groups take the maximum, it is judged as unidentifiable. A rule in which "C_{ij}^k" of pattern classes is unclassifiable is regarded as a dummy rule. It does not affect fuzzy inference. When the pattern group CX can be determined uniquely, the pattern class group CX obtained by Eq. (3) is regarded as the conclusion of the fuzzy if--then rule C_{ij}^k.

(3) Computation of confidence value CF_{ij}^k

The confidence value CF_{ij}^k of a fuzzy if--then rule is calculated using the following equation when the pattern class group CX is not identifiable.

$$CF_{ij}^k = \left| \beta_{CX} - \beta \right| \Big/ \sum_{t=1}^{M} \beta_{ct} \qquad (4)$$

$$\beta = \sum_{t=1, ct \neq CX}^{M} \beta_{ct} / (M-1) \quad (5)$$

Therein, M is the number of pattern classes.

A confidence value CF_{ij}^{k} takes a value within a set of $[0\ ,1]$. For example, in a certain fuzzy space, the confidence value CF_{ij}^{k} is 1.0 when patterns by a fuzzy if--then rule belong to all pattern groups CX, otherwise $CF_{ij}^{k} < 1.0$ when they belong to multiple pattern groups.

3.2.2 Classification Rule of Fuzzy If-Then Rules

Classification rules for identifying unknown patterns given by generated fuzzy if-then rules are presented next.

(1) Compute the maximum of the product of fitness and the confidence value α_{ct} for each group using the following equation.

$$\alpha_{ct} = \max\left\{ \mu_i^K\left(x_{p1}\right) \cdot \mu_j^K\left(x_{p2}\right) \cdot CF_{ij}^K \middle| C_{ij}^k = Ct \right\} \quad (6)$$

(2) Compute the group CX that maximizes α_{ct} by the following equation.

$$\alpha_{ct} = \max\left\{ \alpha_{C1}, \alpha_{C2}, \cdots, \alpha_{CM} \right\} \quad (7)$$

When multiple groups take the maximum, the unknown pattern x_p is judged unidentifiable. Usually, an overly coarse fuzzy partition of a pattern space hinders complicated classification, although an overly fine partition yields too many fuzzy if-then rules.

3.2.3 Training Rules of Fuzzy If-then Rules

The classification capability of a fuzzy pattern recognition system is affected by the method of fuzzy partitioning of a pattern space. The trainable fuzzy classification procedure is applied to improve fuzzy classification ability; it corrects the confidence value of the generated fuzzy if-then rules successively according to a training pattern. Successive modification of the confidence value CF_{ij}^{k} is implemented using the following equation.

1) If the conclusion CF_{ij}^{K} is in agreement with a group to which the training pattern x_p belongs, then $CF_{ij}^K = CF_{ij}^K + \eta_1\left(1 - CF_{ij}^K\right)$ (8)

2) If the conclusion CF_{ij}^{K} is not in agreement with a group to which the training pattern

x_p belongs, then $CF_{ij}^K = CF_{ij}^K - \eta_2 CF_{ij}^K$ (9)

In those equations, η_1, η_2 are the training coefficients. The former provides the magnitude of reward given to a rule of right classification, whereas the latter provides the magnitude of a penalty given to a rule of wrong classification.

Optimization of the calculation of membership functions that are related to the number of if-then rules is conducted under conditions that maximize the following objective function in the pattern classification computation using training data.

$$f(S) = w_{ncp} \cdot NCP(S) + w_{cf} \cdot CF(S) - w_d \cdot DR(S) \quad (10)$$

Therein, w_{ncp} is the weighting factor of the number of correct answer recognition patterns, $NCP(S)$ stands for the total number of correct answer classification patterns, w_{cf} represents the weighting factor of a confidence value, $CF(S)$ denotes the sum of confidence values, w_d is the weighting factor of a dummy rule, and $DR(S)$ signifies the total number of dummy rules.

The trainable fuzzy classification procedure applied in this study has features that it can accommodate ambiguity as an input factor, and that acquired inference rules are evaluated with respect to a confidence value. Because it is applicable even to a landslide phenomenon of multiple movement types, this method is regarded as having high versatility for Landslide Classification.

3.3 Attribute Factors of HCMR Used for Prediction of Landslide Classification

3.3.1 Geological Features

The subject of this study, the HCMR, runs north to south parallel to the border with Laos. It is located in the mountains of central Vietnam, ranging in elevation from 60m to 1000 m. Near Prao, HCMR is adjacent to the border. Between Prao and A Ruoi, it is adjacent to several mountain passes. Consequently, the road has many curves. However, along the rivers between the mountain passes is 40 thin, flat terrain with scattered settlements. The annual rainfall in the area partly reaches 4000mm/year areas in the Central of Vietnam (Tien D. V. et al., 2014).

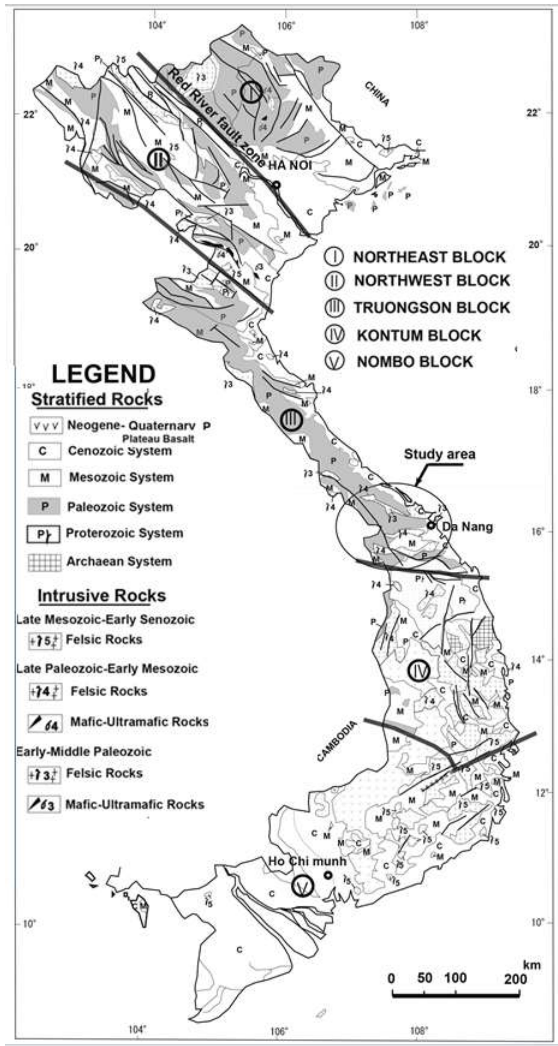


Fig. 3.2 Geological Tectonic Division of Vietnam (Tran, 1995)

In terms of geological structure, Vietnam's geological features are divided into six categories: Northeast Block, 45 Northwest Block, Truong Son Block, Kontum Block, and Nambo Block (Fig 3.2). The boundaries are Truong Son Block and Kontum Block, with geological features and structures that differ greatly in the northern and southern parts. Paleozoic and Mesozoic rock layers are much widespread in the northern part of Vietnam than in the southern part. The areas have numerous faults and complex geological structures. The south has Proterozoic rock enclosing Archeozoic rock, known as the Kontum massif, at around 14°N latitude. Hardly any Paleozoic rock is 55 distributed south of this basement rock. Basaltic plateaus that erupted between the Neogene and Quaternary era are found near the western borders (Tran, 1995); (JOGMEG - Japan Oil, 2000).

Of the geological categorizations of Vietnam described above, the geological features of the southern part known as the "Truong Son Block" area are the focus of this study (Fig. 3.2). In the study area, the geological features of the northern part mainly comprise sedimentary rocks such as mudstone, siltstone, sandstone, conglomerate, limestone, marl, and shale from the Paleozoic, metamorphic rock consisting largely of quartz schist and mica schist from the Paleozoic, as well as granite.

The distribution of these shows a tendency for arrangement in a northwest–southeasterly direction parallel to the HCMR. From 16°N to around 15° 30'N in a southerly direction, the geological features at the center of the study area mainly comprise those of sedimentary rock such as mudstone, sandstone, conglomerate, shale, and limestone of the Mesozoic. On the sloping surfaces of this area, cuesta land formations and gentle slopes reflecting the homoclinal structure of the stratum can be found in abundance. Layers of coal between 10 cm and several meters thick are 10 presented between these sedimentary rocks.

Paleozoic and Mesozoic granite is widespread across the study area overall. Metamorphic rock with hardened Hornfels can be found in this area (Fig 3.3).

3.3.2 Type Classification of Landslides

The authors have reported the motion type and geological background of landslides at 181 sites investigated in field observations along the HCMR in the study area (Tien, D. V. et al., 2015).

Their motion types are classified into the following six categories (Fig. 3): rock fall, translational rockslide, translational wedge type slide, translational shallow debris slide, rotational slide and gulley type slide or flow. The classification is based on the motion types of fall, slide, and flow by (Varnes, 1978), considering special types occurring under strong effects of geological and geologic structures and terrain of the concerned sites. Beside traditional movement, some types have partial features; translational wedge type slide is described as a moving block slips out into a triangular shape. The translational shallow debris slide is described as a debris with thickness less than 1 m that slides down on a bedrock. The gulley type slide and flow is predicted as a moving block of a circular slide occurring on the upper part of a slope that slides down on the slope, as in a gulley with fluxing action resembling in appearance (Fig. 3.4).

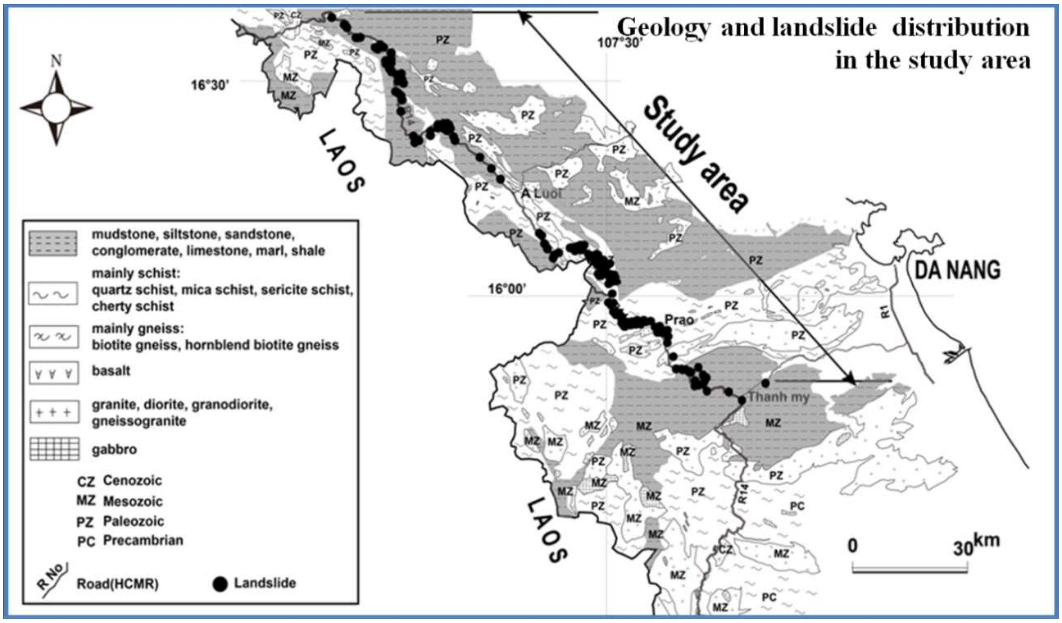


Fig. 3.3 Geology and landslide in the study area (Tien, D. V. et al., 2015)

These types were established also considering that the situation of a slope disaster on a road can be understood easily especially by engineers and researchers engaged in a disaster. For that reason, this classification is applicable to this study region only.

3.3.3 Attribute Factors of Classification

The attribute factors of classification include topographic features such as the geological and geologic structure features of a slope, the weathering feature of the ground, the occurrence scale of a landslide, relevance with related rivers in the corrosion power that causes a geological change of a slope, and the slope angle, which is related to the slope stability. Factors associated with classifications are defined as follows.

No. 74, translational shallow debris slide; No. 10, Translational rock slide; No. 8, Rotational slide; No. 79, Translational wedge type slide; No.72, Gulley type slide and flow from Abe etc., 2014.

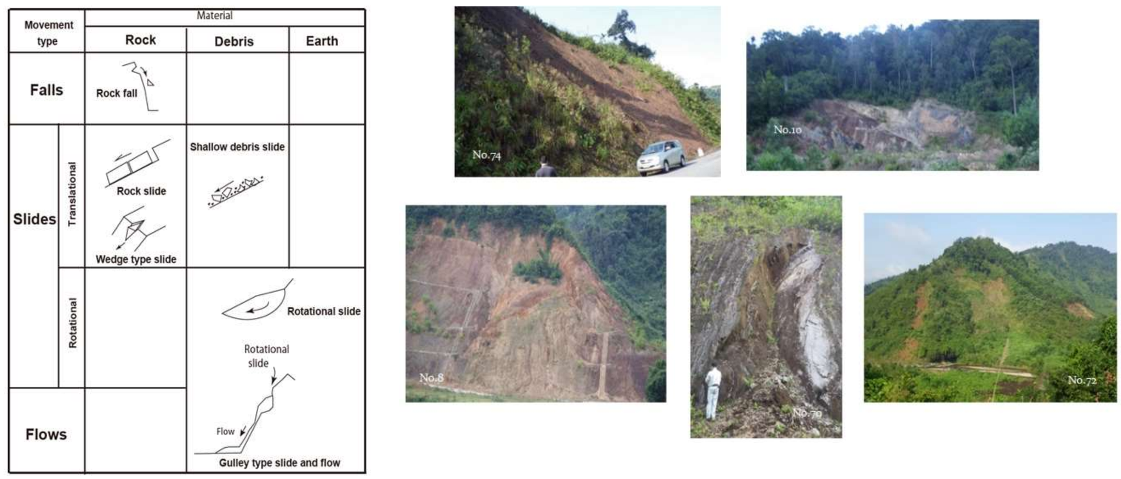


Fig. 3.4 Moving types of landslides along HCMR

3.3.3.1 Geological and Geologic Structure Features

The geology along the HCMR as the study area is classifiable roughly into Paleozoic sedimentary rock regions, Paleozoic metamorphic rock regions, and Mesozoic sedimentary rock regions as described above. In addition to these, granite and granitic gneiss (hereinafter, granite/gneiss) are scattered throughout the region. These geologies serve as landslide causative factors with special geological features including development of cracks such as bedding, schistosity, joints, and faults, hard and soft properties of bedrock, and rainwater permeability (Abe, 2014). Herein, we discuss the following factors especially related to a landslide: granite/gneiss, schist, Mesozoic sedimentary rock (mudstone, sandstone, and conglomerate), Paleozoic sedimentary rock (shale, mudstone, sandstone, and mudstone), and Hornfels.

3.3.3.2 Weathering Features of Slope Bedrock

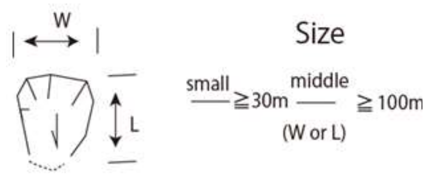
Weathering varies the property of inclined bedrock-to-bedrock, pebbles, and soil according to the extent that it affects landslide form. The weathering here is classified in to brown to yellow soil as "very strong", soil containing gravel as "strong", rock with partially open cracks as "weak", and fresh bedrock as "un-weathered."

3.3.3.3 Topographic Features

Most landslides have occurred on a scale 30 m or less, but those of a scale of 100 m or more have been observed at several sites. Accordingly, landslides of a width or length of 100 m or more are classified as "large", those of more than 30 m and less than 100 m as "middle", and those of 30 m or less as "small" (Fig. 3.5).

Corrosion at the slope end by a river affects the slope stability greatly. It is designated as the attack slope of a river when the flow direction of a river goes to the lower end of a slope (Fig.3.6), otherwise designated as the non-attack slope of river. Moreover, because the watershed of the scale and position of river that might affect the present slope, it is defined as non-river when the slope is 100 m or more distant from the river.

Table. 3.1 Geological and topographical attribute factors of road slope disaster



Classification of scale of landslide

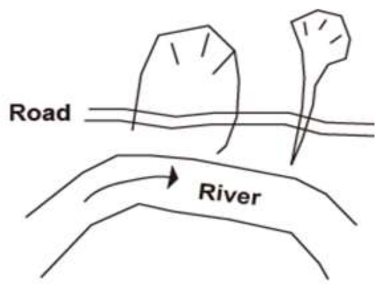


Fig. 3.5 Relation between river and landslide slope-figure shows attack slope-

Movement Type	1	Translational Rock Slide	
	2	Rotational slide	
	3	Translational Wedge Slide	
	4	Gulleytype slide & Flow	
	5	Rock fall	
	6	Translational shallow debrid slide	
Geology	1	Garnit/Gneiss	
	2	Schist	
	3	Mesozoic : Mudstone, sand stone, conglomerate	
	4	Paleozoic : shale,mudstone,sand stone, limestone	
	5	Homfels	
Weathering	1	Very strong	Soil
	2	Strong	Gravel
	3	Weak	With many crack
	4	Unweathering	Fresh
Scale	1	Large	(W)or (L)>100m
	2	Middle	30m<=(w) or (l)>
	3	Small	(w)or (L)<30m
Relation with Stratum	1	Dip Slope	
	2	Pposit dip slope	
	3	Hoprizontal stratum	
Relation with River	1	Attack slope of river	
	2	Non attack slope of river	
	3	Non river (<100m)	
Slope angle	1	10 dig	
	2	(11 to 30) dig	
	3	(31 to 50) dig	
	4	51 dig and upper	

The road slope angle is formed by geological causative factors and artificial planning at the time of road development, so that it relates to landslide form or disaster scale to a road. The slope angle is difficult to measure at a controlled condition because the angle often changes in the middle of a slope and each slope length differs. Slope angle is computed from contour lines in a certain scale of meshes on the topographic map of the area of frequent landslides in this study. The slope angle was classified roughly into 0–10°, 11–30°, 31–50°, and 51° or greater.

The dip direction of a stratum might have a large effect on slope disaster damage to a road aside from these factors. However, that point is not discussed here because severe weathering of the metamorphic rock and granite/gneiss regions renders measurement difficult in many cases. The feature distribution of these attribute factors is presented in Table 3.1

3.4 Analysis of Landslide Classification

3.4.1 Predictive Accuracy of Landslide Classification

Landslide Classification with fuzzy if--then rules is conducted by inference rules as the combination of attribute factors. For this study, 181 on-site landslide data, which were collected along the HCMR, was used as basic data. The analysis was conducted using 156 of those sites as teacher data of a predictive model. The remaining 25 sites were used as identity data for predictive accuracy. Table 3.2 presents the results of type classification analyses by teacher data.

It also shows together the multi-group linear discriminant analysis that classifies each group so that the generalized Mahalanobis distance between each landslide type group is minimized. This result shows a hitting ratio of 67% or over of Landslide Classification. The comprehensive hitting ratio of Landslide Classification by the neuro-fuzzy analysis is higher by about 8% than the multi-group linear discriminant analysis. Classification analysis of landslide types could not be conducted for wedge type slide or rock fall because too few teacher data were available for investigating the combination of each attribute factor.

Table. 3.2 Analysis of Landslide Classification by fuzzy if-then rules

(156 teaching Data)

	landslide types	Total No.	Correct No.	Hitting ratio(%)	Landslide types				
					Translational (G1)	Rotational (G2)	Wedge (G3)	Gully (G4)	Rock (G5)
Neuro-fuzzy analysis	Translational(G1)	45	42	93.30	42	3	0	0	0
	Rotational(G2)	49	41	83.67	1	41	0	7	0
	Gully(G4)	40	27	67.50	4	9	0	27	0
	Total	134	110	82.10	47	53	0	34	0
Linear discriminant analysis	Translational(G1)	45	33	73.30	33	3	7	0	2
	Rotational(G2)	49	38	77.56	3	38	0	8	0
	Gully(G4)	40	28	70.00	3	9	0	28	0
	Total	134	99	73.88	39	50	7	36	2

The solution parameters of the genetic algorithm for partition of a classification space and identification of inference rules in the neuro-fuzzy analysis were 100 bions per generation, for 1000 generations, a mating rate of 50%, and a mutation rate of 50%. The optimum solution was obtained within iterations through about 100 generations.

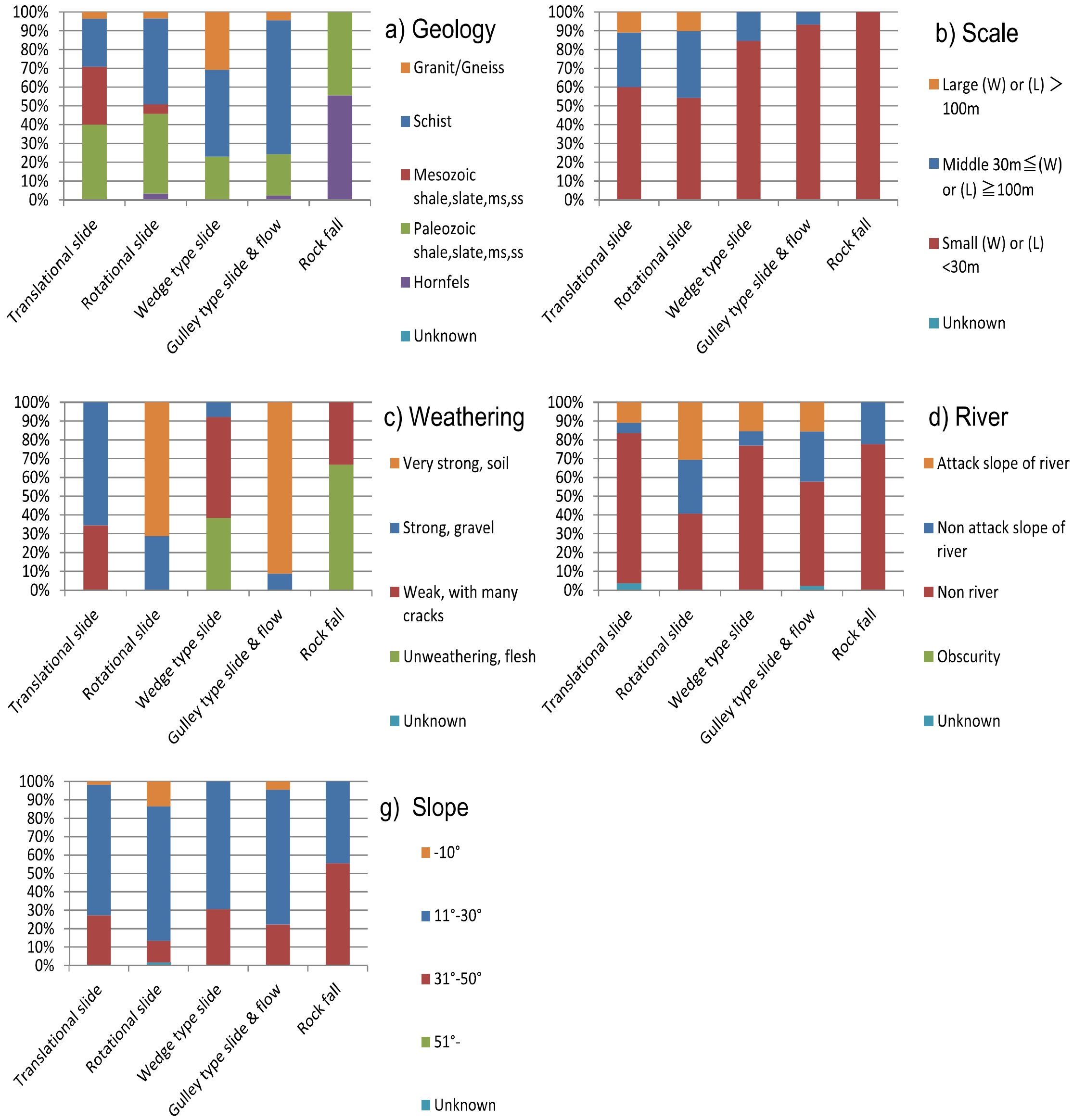


Fig. 3.6 Distributive characteristics of attribute factors for each landslide type

The neuro-fuzzy analysis classified the surface slide of a gulley type slide as a small-scale rotational slide, with a poor hitting ratio of 67.5%. However, the hitting ratios of classification of a translational slide with weak weathering and a rotational slide with strong weathering were very high, 83% or more, so that it was verified that the prediction of a Landslide Classification is possible. A hitting ratio of about 70% was obtained in general in the Landslide Classification by multi-group linear discrimination. However, because the confidence values were almost equal, little difference was found between classification capabilities among landslide types.

Table. 3.3 Landslide Classification result (Gully type slide)

Site No.	Neuro-Fuzzy analysis		Linear discriminant analysis		Site No.	Neuro-Fuzzy analysis		Linear discriminant analysis	
	Measure – Analysis	Confidence Value	Measure – Analysis	Confidence Value		Measure – Analysis	Confidence Value	Measure – Analysis	Confidence Value
1	4-2	1.000	4-2	0.147	21	4-4	1.000	4-4	0.137
2	4-4	0.783	4-4	0.185	22	4-4	0.431	4-4	0.176
3	4-2	0.376	4-2	0.122	23	4-2	0.483	4-2	0.172
4	4-4	1.000	4-4	0.103	24	4-4	0.692	4-4	0.133
5	4-4	0.692	4-4	0.133	25	4-4	0.692	4-4	0.133
6	4-1	0.451	4-4	0.069	26	4-4	0.692	4-4	0.133
7	4-1	0.395	4-1	0.061	27	4-4	0.692	4-4	0.133
8	4-4	0.692	4-4	0.133	28	4-4	0.659	4-4	0.172
9	4-4	0.692	4-4	0.133	29	4-4	0.659	4-4	0.178
10	4-4	0.860	4-4	0.136	30	4-4	0.659	4-4	0.172
11	4-4	0.520	4-4	0.101	31	4-4	0.659	4-4	0.172
12	4-2	0.715	4-2	0.166	32	4-4	0.783	4-4	0.185
13	4-4	1.000	4-4	0.158	33	4-4	0.804	4-4	0.181
14	4-2	0.683	4-2	0.100	34	4-4	0.783	4-4	0.174
15	4-2	0.715	4-2	0.125	35	4-4	0.659	4-4	0.173
16	4-1	0.645	4-1	0.060	36	4-4	0.783	4-4	0.174
17	4-2	0.683	4-2	0.100	37	4-4	0.659	4-4	0.172
18	4-2	0.683	4-2	0.100	38	4-4	0.659	4-4	0.178
19	4-4	0.692	4-4	0.133	39	4-2	0.483	4-2	0.170
20	4-4	1.000	4-4	0.137	40	4-1	0.216	4-1	0.063

The distributive characteristics of attribute factors for each Landslide Classification are presented in Fig 3.7. Table 3.3 presents confidence values for the type classification analysis of gulley-type landslides with poor predictive accuracy obtained by Eq.(4). Hatched cells for Measure - Analysis in this table represent inconsistency between type classifications by measurement and by analysis, which indicates that classification disagreement in landslide types by the neuro-fuzzy and linear discriminant methods generally occurs in the same areas.

Nevertheless, a great difference in the confidence value in Eq. (4) shows that the multi-group linear discriminant analysis performs the classification with very few values. Because the linear discriminant method conducts the analysis by the linear sum of weight value of each attribute factor as opposed to the neuro-fuzzy method, classifying types with the combination of each attribute factor of a slope.

Multi-group linear discriminant equations acquired in this analysis are the following.

Translational type slide (G1):

$F(G1)=-43.403+3.184*X1+9.974*X2+16.098*X3+5.534*X4+0.631*X5$,

Rotational type slide (G2):

$F(G2)=-26.493+3.016*X1+8.684*X2+10.256*X3+4.355*X4+0.671*X5$, and

Gulley type slide (G4):

F(G2)=-29.321+2.169*X1+10.495*X2+9.675*X3+4.724*X4+0.968*X5,

Where X1–X5 are slope attribute factors. These demonstrate that the weighting factor of each attribute factor of a slope is almost equal, and there is little difference in the confidence values by the multi-group linear discriminant method, so that type classification is conducted based on a small difference of discriminant values. This point suggests that the multi-group linear discriminant method requires the careful measurement setting of input attribute factors, and that the neuro-fuzzy method considering ambiguity is beneficial.

3.4.2 Extraction of Identification Rules for Landslide Classification

The total number of fuzzy if-then rules investigated in these analyses are determined by the number of attribute factors of a slope and the number of their partitions as 3,125. However, the number of rules acquired from the maximization conditions of the classification objective function of types by Eq. (10) is only 96. The hitting ratio of type classification was higher than 90% in some cases, as described in the preceding paragraph, so that type classification is possible even with not many classification rules but with a very small number of rules. Consequently, the method of this study is regarded as practical. The fuzzy partition of a pattern recognition space acquired by training is depicted in Fig. 6. Attribute factors other than slope angle are presumed to have fewer partitions of a membership function.

Table 3.4 is the linguistic expression of if-then rules with a high confidence value determined by the distribution of this membership function. The top three cases there of generate the following if-then rules as linguistic expressions.

1) If a slope has granite/gneiss geology, is of a large-scale, weakly weathered, of an angle of 30° or less, and is an attack slope along a river, then its landslide type is translational slide. The confidence value of this representation is 1.000.

2) If a slope has granite/gneiss geology, is of a large-scale, weakly weathered, of an angle of 30° or less, and is a non-attack slope along a river, then its landslide type is translational slide. The confidence value of this representation is 1.000.

3) If a slope has schist geology, is of a large scale, weakly weathered, of an angle of 30° or less, and is an attack slope along a river, then its landslide type is translational slide. The confidence value of this representation is 1.000.

These if-then rules of type classification indicate that attribute factors of weathering and geology are necessary for Landslide Classification. Examination of the fuzzy if-then rules thus obtained enables estimation of the importance of combined attribute factors in Landslide Classification.

Table. 3.4 If-then rules obtained by fuzzy recognition analysis

Landslide types	Input slope factoers					Confidence values
	Geology	Scale	Weathering	Slope angle	River	
Translational slide	1 Granite/Gneiss	1 Large	3 Weak	3 D≦30°	1 Attack	1.000
Translational slide	1 Granite/Gneiss	1 Large	3 Weak	3 D≦30°	2 No attack	1.000
Translational slide	2 Schist	1 Large	3 Weak	3 D≦30°	1 Attack	1.000
Translational slide	2 Schist	1 Large	3 Weak	4 D≦30°	2 No attack	1.000
Rotational slide	2 Schist	1 Large	1 Very strong	3 D≦30°	1 Attack	0.932
Rotational slide	1 Granite/Gneiss	1 Large	1 Very strong	1 D≧60°	1 Attack	0.857
Rotational slide	2 Schist	1 Large	1 Very strong	1 D≧60°	1 Attack	0.849
Gully type slide	1 Granite/Gneiss	2 Middle	1 Very strong	3 D≦30°	2 No attack	0.451
Gully type slide	1 Granite/Gneiss	2 Middle	1 Very strong	1 D≧60°	2 No attack	0.445
Gully type slide	1 Granite/Gneiss	2 Middle	1 Very strong	4 Obscurity	2 No attack	0.438

The importance of factors for type classification is extracted by the combination of each factor of a slope in the fuzzy classification analysis, whereas a weighting factor is extracted for each factor by multi-group linear discriminant equations: the F value, which verifies whether a certain specific explanatory variable is useful for classification, is 132.1 for weathering, 53.0 for geology, 37.2 for scale, 27.7 for slope angle, and 21.5 forever. Consequently, it is presumed that the attribute factor of weathering is extremely important in Landslide Classification: its weight has significance that is 2.5 times that of other attribute factors.

3.4.3 Prediction of Landslide Classification

To examine the applicability of the classification procedure of Landslide Classification of this study, fuzzy if-then rules for classification were generated from training data. Then the Landslide Classifications of 25 unlearned areas were investigated using these generated fuzzy if-then rules. Table 3.5 presents the analysis results of type classification by the non-training data.

The result demonstrates the higher predictive accuracy of the fuzzy classification analysis than the multi-group linear discriminant method. The multi-group linear discriminant method was unable to identify an unlearned Landslide

Classification. The confidence value in this identification was extremely small: 0.02–0.04. Then they were classified to slide or rock fall.

Table. 3.5 Analysis of Landslide Classification by fuzzy if-then rules using

	Landslide types	Total No.	Correct No.	Hitting ratio(%)	Landslide types				
					Translational (G1)	Rotational (G2)	Wedge (G3)	Gully (G4)	Rock (G5)
Neuro-fuzzy analysis	Translational(G1)	10	10	100.0	10	0	0	0	0
	Rotational(G2)	10	6	60.0	0	6	0	4	0
	Gully(G4)	5	4	80.0	0	1	0	4	0
	Total	25	20	80.0	10	7	0	8	0
Linear discriminant analysis	Translational(G1)	10	0	0.0	0	1	7	2	0
	Rotational(G2)	10	1	10.0	6	1	3	0	0
	Gully(G4)	5	0	0.0	4	0	1	0	0
	Total	25	1	4.0	10	2	11	2	0

This resulted from Landslide Classification based on the slight difference of classification predicted value by the sector sum of various factors as described above. However, because the fuzzy analysis carries out Landslide Classification with the combination of each factor, analysis is conducted according to the interaction of factors with significance for type classification. These results suggest that the fuzzy theory of this study allows landslide-type classification at roadside slopes of the HCMR, and that it has high applicability to local sites because of ambiguity examined. Therefore, it is an economical method.

3.5 Conclusions

A procedure for Landslide Classification was investigated for the implementation of efficient and economical maintenance management for the planning of preventive-measures works against slope landslide disasters at roadside slopes along the HCMR. The following conclusions were obtained.

1) Few studies of Landslide Classification have been conducted to date. No elaborate or economic survey has been conducted to formulate or assess preventive measures. Accordingly, a Landslide Classification procedure using fuzzy theory considering ambiguity was examined for implementing high precision, economical, on-site inspection. We have demonstrated that the type classification procedure based on fuzzy if--then rules is beneficial through comparison with the multi-group linear discriminant method.

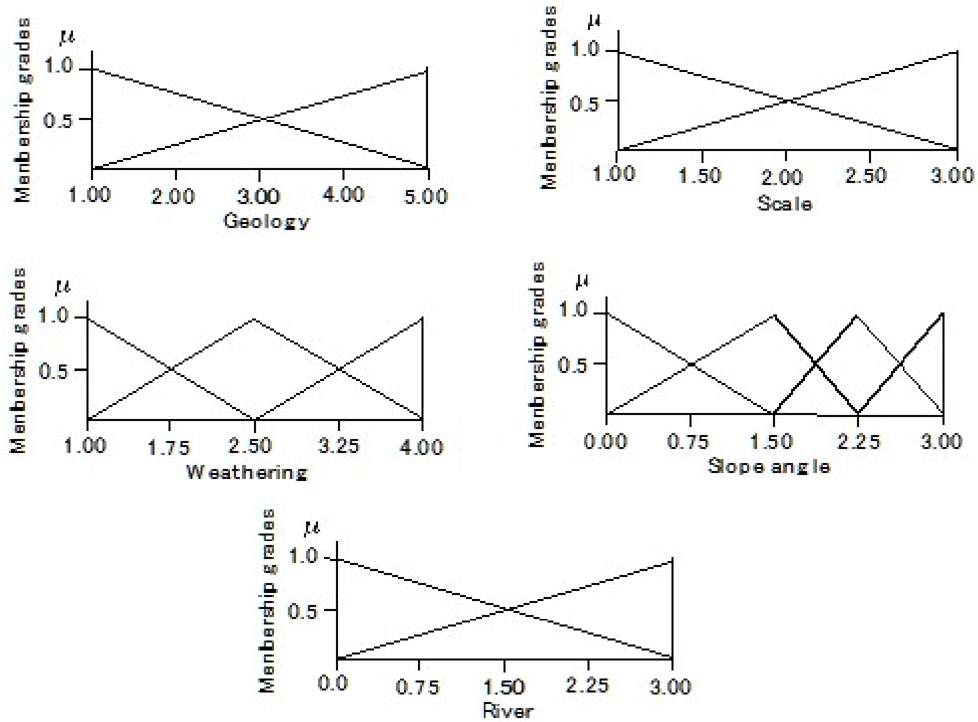


Fig. 3.7 Shape of membership function acquired by training

2) Because the classification procedure by fuzzy if-then rules differentiates confidence values in Landslide Classification, the importance of the combination of attribute factors can be estimated. We have shown that the linguistic expression of if-then rules on the combination of these attribute factors is easy to understand for general engineers because it resembles human reasoning processes.

3) Weathering, Geology, and Scale are important attribute factors in Landslide Classification at roadside slopes of the HCMR; the landslide types can be ascertained. Future tasks include accumulation of many more data for training for additional precision improvement in Landslide Classification, was well as additional examination of attribute factors effective in classification.

CHAPTER 4 – GEOLOGICAL MECHANISMS OF LANDSLIDES GENERATING ALONG HCMR IN THE CENTRAL OF VIETNAM (Tien, D. V. et al., 2015)

4.1 Introduction

In the Central of Vietnam, the HCMR runs from south to north along the border with Laos. In this area, the HCMR is often closed because of numerous landslides that occur during the rainy season. Consequently, an urgent need exists to elucidate the landslide generation mechanism of and to conduct risk assessment. This study specifically examines landslides occurring at approximately 180 locations along the 150 km distance (linear distance) from Thanh My (west of Da Nang City) and the intersection with National Route 9 (west of Quang Tri). The landslides are classified based on the type of movement to ascertain the triggering mechanism. This survey was administered during 2012–2014.

The type of landslide movement in this area differs significantly depending on whether the area is a Paleozoic sedimentary and metamorphic zone or a Mesozoic sedimentary zone. In a Paleozoic sedimentary and metamorphic area, weak aspects such as schistosity, beddings, faults, and joints associated with geological structures become shear planes. Translational slides (wedge type) and rotational slide and flow (gully type) occur often in this area, with infiltration of the surface water and weathering of rocks as the causes. In the Mesozoic sedimentary area, translational rockslides are most common, where coal layers are disrupted by fold structures as the slip surface. Results show that these landslides are not caused simply by heavy rain and weathering typical of the tropics. Rather they are closely associated with geology, geological structure, and cuesta topography.

4.2 Study Area Outline and Geological Features

The subject of this study, the HCMR, runs north to south parallel to the border with Laos. It is located in the mountains of central Vietnam, ranging in elevation from 60 m to 1000m (Fig.4.1). Near Prao, HCMR is adjacent to the border. Between Prao and A Ruoi, it is adjacent to several mountain passes. Consequently, the road has many curves. However, along the rivers between the mountain passes is thin, flat terrain with scattered settlements. The annual rainfall in the area partly reaches 4000–4500mm/year in some areas in the Central of Vietnam.

In terms of geological structure, Vietnam's geological features are divided into six categories: Northeast Block, Northwest Block, Truong Son Block, Kontum Block, and Nam Bo Block (Fig.4.2).

The boundaries are Truong Son Block and Kontum Block, with geological features and structures that differ greatly in the northern and southern parts. Paleozoic and Mesozoic rock layers are much more widespread in the northern part of Vietnam than in the southern part. The areas have numerous faults and complex geological structures.

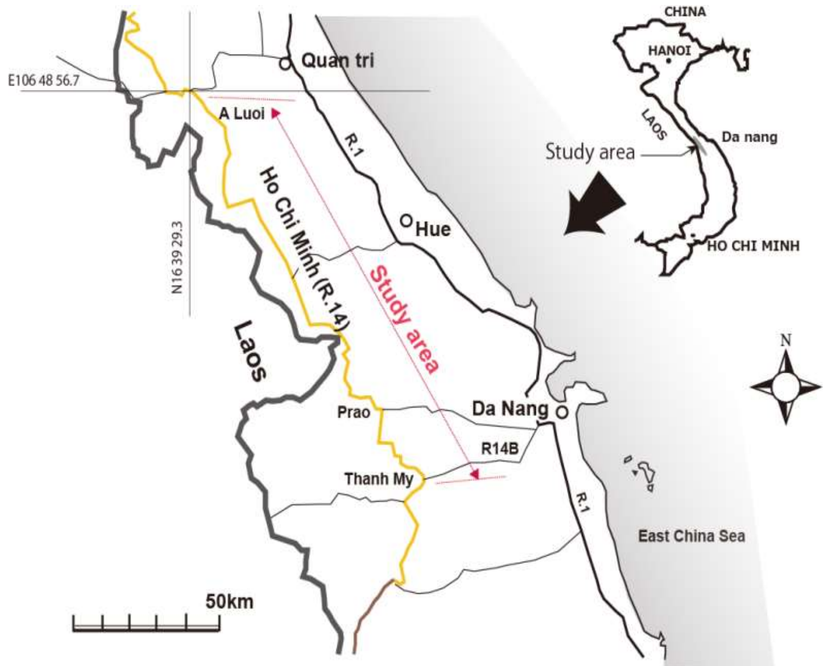


Fig. 4.1 Study area

The south has Proterozoic rock enclosing Archeozoic rock, known as the Kontum massif, at around 14°N latitude. Hardly any Paleozoic rock is distributed south of this basement rock. Basaltic plateaus that erupted between the Neogene and Quaternary era are found near the western borders (Tran, 1995); (JOGMEG - Japan Oil, 2000).

Of the geological categorizations of Vietnam described above, the geological features of the southern part known as the "Truong Son Block" area are the focus of this study (Fig 4.2). In the study area, the geological features of the northern part mainly comprise sedimentary rocks such as mudstone, siltstone, sandstone, conglomerate, limestone, marl, and shale from the Paleozoic, metamorphic rock consisting largely of quartz schist and mica schist from the Paleozoic, as well as granite.

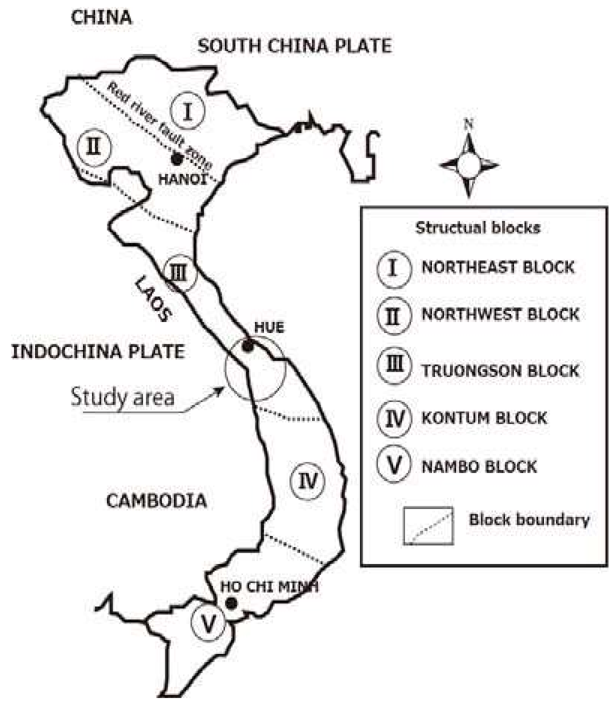


Fig. 4.2 Geological tectonic divisions of Vietnam (Tran, 1995)

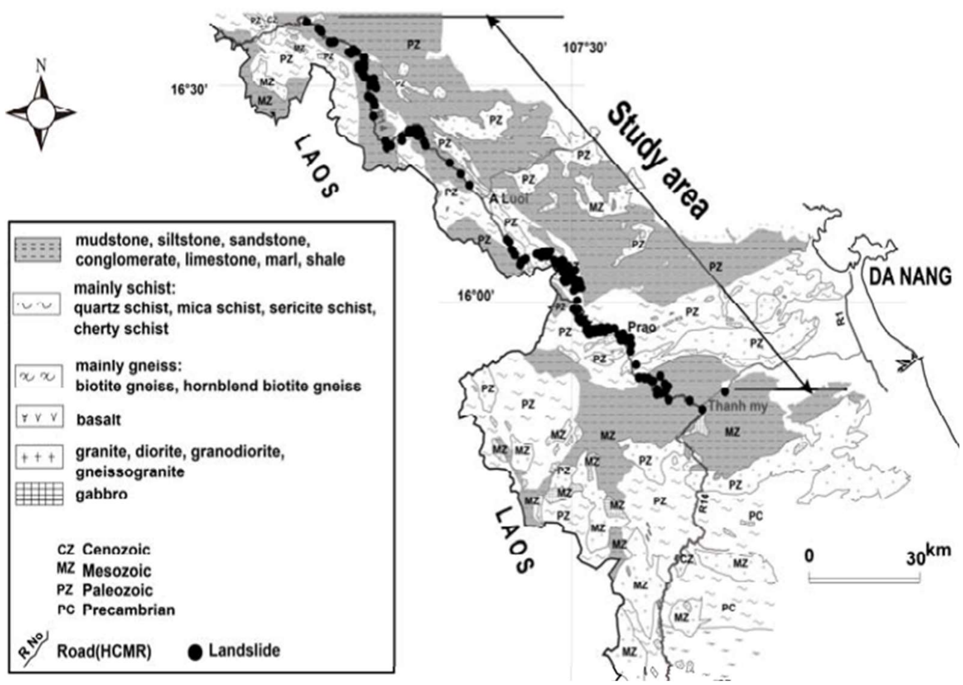


Fig. 4.3 Geological map of the study area based on (Tran, 1995)

The distribution of these shows a tendency for arrangement in a northwest–southeasterly direction parallel to the HCMR. From 16°N to around 15° 30'Nin a southerly direction, the geological features at the center of the study area mainly comprise those of sedimentary rock such as mudstone, sandstone, conglomerate, shale, and limestone of the Mesozoic. On the sloping surfaces of this area, cuesta land formations and gentle slopes reflecting the homoclinal structure of the stratum can be found in abundance. Layers of coal between 10cm and several meters thick are presented between these sedimentary rocks.

Paleozoic and Mesozoic granite is widespread across the study area overall. Metamorphic rock with hardened Hornfels can be found in this area (Fig4.3).

4.3 Landslide Moving Types and Geology

4.3.1 Landslide Movement Classification and Types

Our site reconnaissance confirmed 182 landslides along the HCMR (Fig.4.3). In principle, we followed the classification of (Varnes, 1978) for landslide movement types.

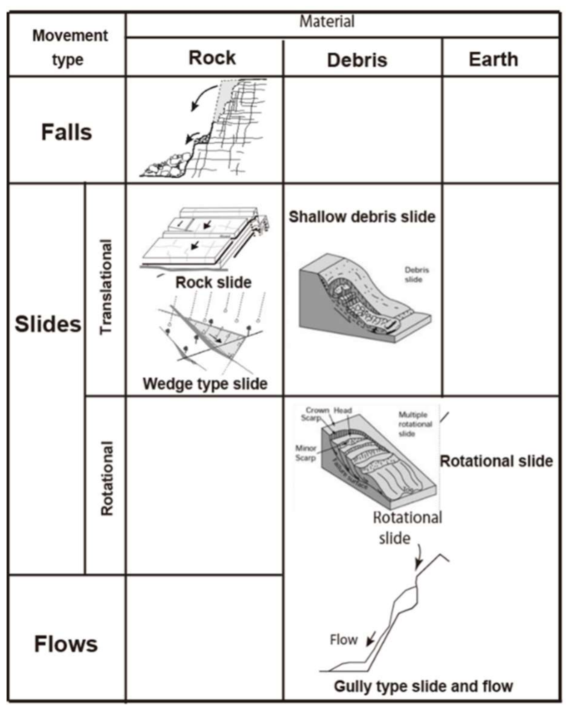


Fig. 4.4 Moving types of landslides along HCMR

However, we classified it in six categories originally from the characteristics of the landslide shapes affected the road. Consequently, the following three landslide classifications were added to translational rockslides, rotational slides, and rock falls. They are 1) translational wedge type slides, by which a moving mass slides in a triangular form; 2) translational shallow debris slides, by which debris of less than1m thickness slides down the bedrock; and 3) gully type slides and flows, by which an arc-shaped sliding mass originating at the upper area of a slope slides down the slope surface, and the morphology resembles an erosional gully (Fig 4.4, Fig 4.5).

Fig. 4.5 Moving types pictures of landslides along HCMR

(No.74: Translational shallow debris slide, No.10: Translational rock slide, No.8: Rotational slide, No.79: Translational wedge type slide, No.72: Gully type slide and flow)

4.3.2 Landslide Moving Type and Geology

The number of landslides based on geology and its percentage show that gully type slides and flows are the most common type at 40% in the areas of schist. Translational shallow debris slides follow. Approximately 70% of landslides in the area of Mesozoic sedimentary rocks are translational rockslides. Rotational slides and translational shallow debris slides are common in the area of Paleozoic sedimentary rocks. Gully type slides and flows are the next common. Approximately 60% of landslides in the area of Hornfels distribution are rock falls. Granitic rock has a small distribution and has few examples of landslides, but landslides of various types do occur, including translational wedge type slides (Fig 4.6).

The relation between geology and landslide movement types is naturally expressed in the differences of landslide movement types for each set of geological features distributed among the study areas.

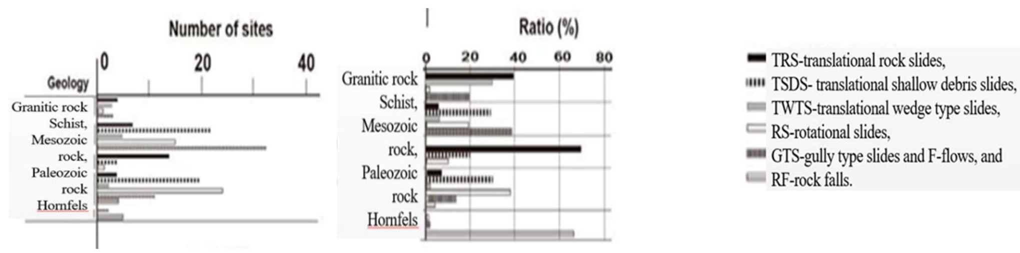


Fig. 4.6 Landslide movement types based on geology

When the study area is divided into northern Paleozoic sedimentary zone (A in Fig 4.7), central Paleozoic metamorphic zone (B in Fig 4.7), and southern Mesozoic sedimentary zone (C in Fig 4.7). The dominant landslide movement types, that are translational shallow debris slides and rotational slides in zone A, gully type slides and flows and translational shallow debris slides for zone B, and translational rock slides in zone C, shows a strong relation with the geology described above(Fig 4.7).

Furthermore, in the Mesozoic sedimentary zone (C in Fig 4.7), cuesta landforms of the same width as the sloped structures and the length of more than 10 km concatenate. Translational rockslides occur commonly within these structures.

4.4 Cracks and Landslides

4.4.1 Cracks in the Bedrock

Cracks referred to here are linear crevasses demonstrated in the bedrock such as joints, faults, bedding, and schistosity. The subjects are a) faults that contain cracks where displacement occurs in the bedrock, and b) joints that exhibit a certain degree of common directionality between multiple cracks, and where displacement does not occur across cracks in the bedrock. The observed cracks are continuous cracks of 1 m or longer.

Landslides occurring in the study area often move along cracks in the bedrock such as bedding, schistosity, faults, and joints. Therefore, for this study, the crack directions in the bedrock were measured in Paleozoic metamorphic rocks (B in Fig 4.7) and Mesozoic sedimentary rocks (C in Fig 4.7).

Cracks and faults in granitic rock outcrop No.7 and schist outcrop No. 485 of Paleozoic metamorphic rocks are concentrated on the first and the third quadrants in the Schmidt net, indicating NW–SE strikes and dips of a high angle (over 60°) (Fig 4.8).

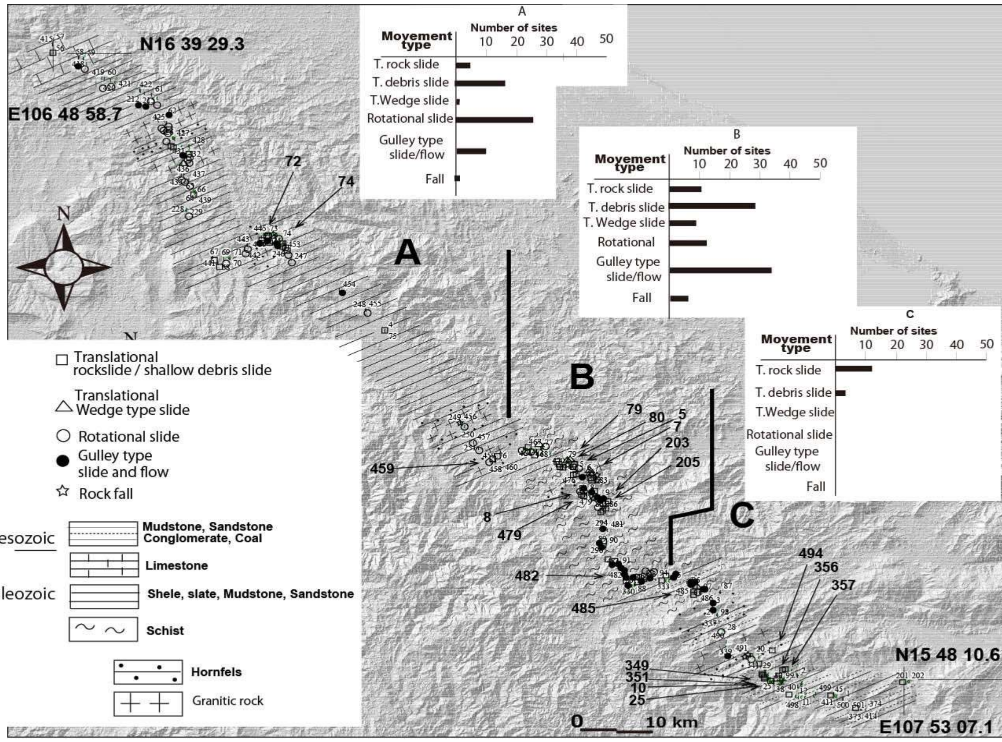


Fig. 4.7 Landslide sites and movement types
(Numbers with an arrow are landslide sites of this paper)

The wedge type slide that is characteristic of this study area moves along the schistosity, joints, and faults. Side scarps of the landslide at No.79 correspond to a fresh schistosity surface (N 30°W, 60°E) and the direction of the joints in the bedrock (N 40°E, 70°W). The trend and plunge of the line that intersects both sides of scarps are N 15°E and 50° based on analysis of the Wulff net. In addition, the side scarps intersect at 80° (Fig 4.9).

The scarps of the wedge type slide that occurred in the outcrop of granitic rock at No.7 correspond to faults and joints. The trend and plunge are N 12° E/40°. The angle at which side scarps intersect is 55° (Fig 4.9).These landslides all use schistosity, joints, or faults as the side scarp, and move perpendicular toward the road with the sliding surface angle of 40–50°. Mesozoic sedimentary rocks consist of sandstone with coal seams and conglomerates.

We observed cracks in sandstone and conglomerate separately from cracks in coal seams and in dark gray mudstones that contain a large amount of carbonates similar to coal seams. The results show that the cracks in coal seams and dark gray mudstone all tend to concentrate in the second and the fourth quadrants in the Schmidt net. Therefore, these cracks have the strike of NE–SW with a dip of 50–60°.

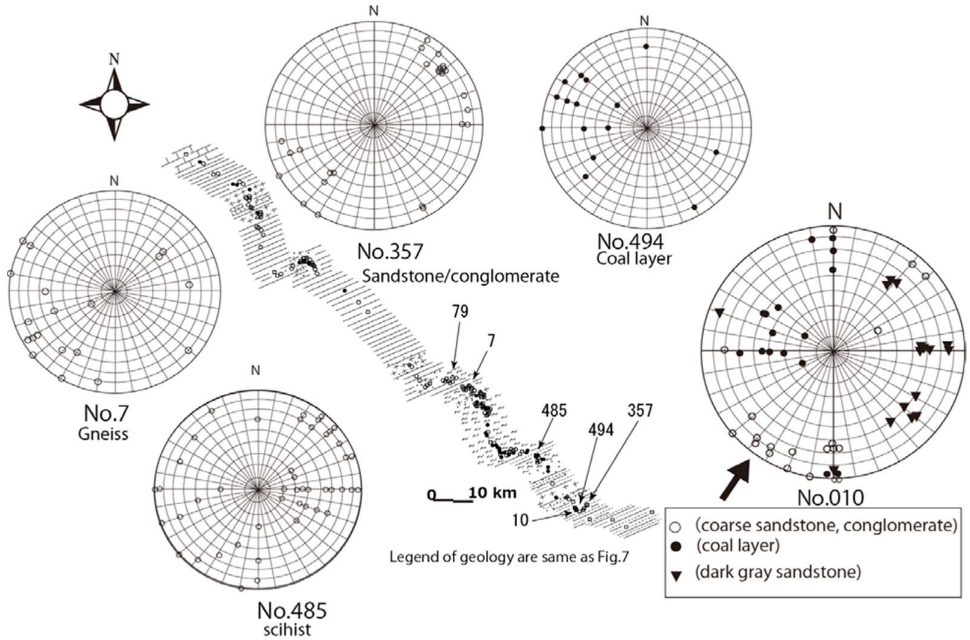


Fig. 4.8 Crack sand faults in the Schmidtnet (Lower hemisphere)

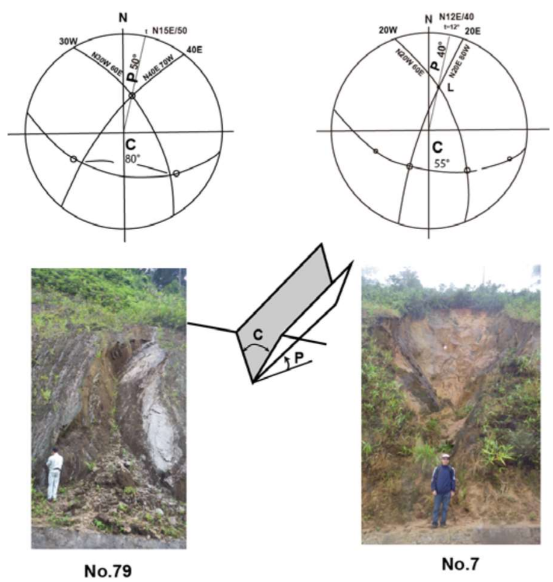


Fig. 4.9 Formation analysis of wedge type slides using theWulffnet

Additionally, cracks in sandstone and conglomerate that contain these coal seams concentrate in the first and the third quadrants in the Schmidt net, having the strike of NW–SE and a dip of more than 60° (Fig. 4.8).

4.4.2 Faults

Sides of landslides occurring in granitic rock and schist correspond to black slickenside with scratches. Slickenside with scratches is often observed also in fractured coal seams of Mesozoic sedimentary rocks. We observed the direction and the angle of faults including these small faults (Fig 4.10).

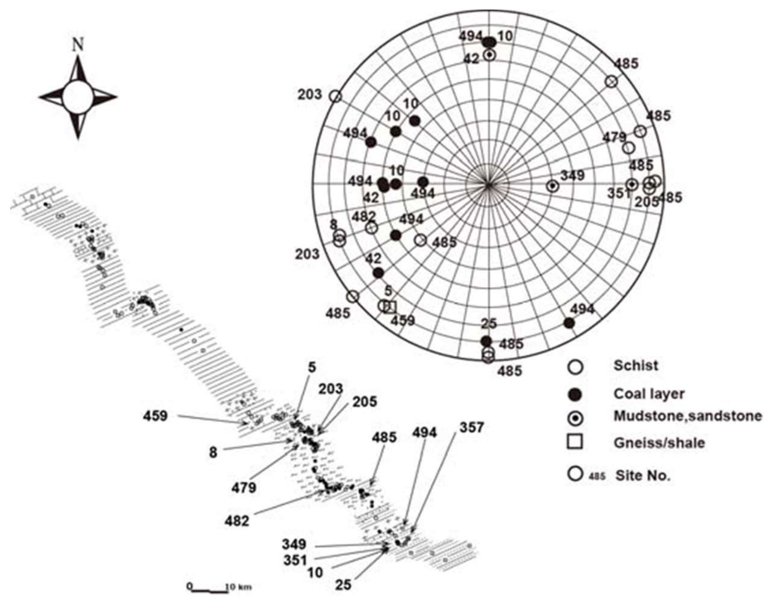


Fig. 4.10 Strike, dip, and distribution of Faults in the Schimidtnet

In Paleozoic metamorphic rocks and Mesozoic sedimentary rocks, faults in mudstone, sandstone, conglomerate, schist, and granitic rock all concentrated in the first and the third quadrants in the Schmidt's net (Fig 4.10). These results excluded coal seams, which implies that these faults have the strike of N–S to NW–SE with a dip of 70–90°.

Small faults within coal seams have strikes scattering, with the dip of low angles (30–80°) compared to faults in other layers. The plunge of the scratches present on the surface of these faults is 60° for schist outcrop No. 203, 50° for No. 479, and 30°, 30°, and 50° for No. 485; all are low angles. The plunge of scratches on the faults in Mesozoic sandstones and conglomerates is also a low angle: 30°.

4.4.3 Cracks and Weathering of the Bedrock

At No. 485, a rocky mass exists with 60m width×15m height × 30 m depth (Fig 4.11). The rock type is weakly metamorphosed muddy-sandy schist. It has the strike of N 70°E with a dip of 70°S. This mass of rock is truncated by a nearly vertical fault trending NW–SE. However, the plunge of scratches on this fault has a low angle: 30–50°.

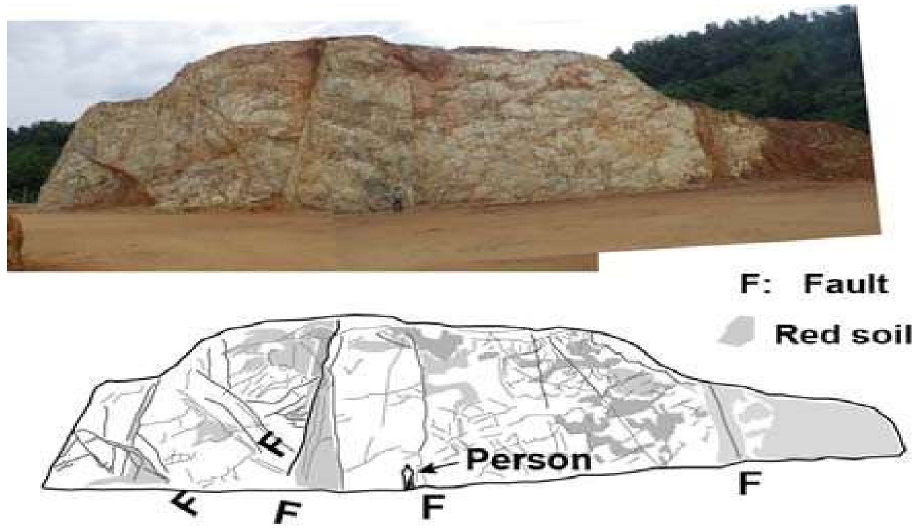


Fig. 4.11 Photographs from the point No.485

Additionally, fine joints are developed in this rock in the same direction as the faults. Reddish-brown soil penetrates deeply along these faults, schistosity, and joints (Fig 4.11). Therefore, rainwater permeates underground along geologically weak surfaces such as faults, joints, and schistosity, enhancing weathering in deeper parts of the bedrock. The X-ray diffraction results of this brown soil identified clay minerals that originate from the metamorphic rocks such as quartz, illite, and kaolinite. The brown color of the soil is likely to derive from a small amount of iron oxide.

4.5 Landslides in Mesozoic Sedimentary Rocks

Landslides in Mesozoic sedimentary rocks differ from the previously described Paleozoic sedimentary rocks and metamorphic rocks, and occur as translational rockslides. Granites are exposed at the border with Paleozoic metamorphic rocks, and contact metamorphic rocks are noted in the surrounding area (Fig 4.7, Fig 4.8).

Sandstone with coal seams and conglomerate are heavily folded in this area. To the south of No. 20 in Fig. 12, cuesta landforms of more than 5 km ×5 km have developed. The HCMR passes through these cuesta cliffs from No. 20 to No .341. To the south of that point, it truncates the west side of cuesta back slopes. Furthermore, near No. 356, it truncates cuesta back slopes. Then it heads south from the area of No.42, arriving in Thanh My. Cracks have formed in sandstone, conglomerate, and coal seams between No. 345 to No. 10 because of heavy folding. Especially, the coal seams are finely fractured (Fig 4.13), forming a structure with a southward dip from the area near No. 10. Before arriving at No. 25, four translation all and slides of 10–50 m width have occurred (Fig 4.14). These landslides move mutually independently using coal seams in sandstone and conglomerate as the sliding surface (Fig 4.15).

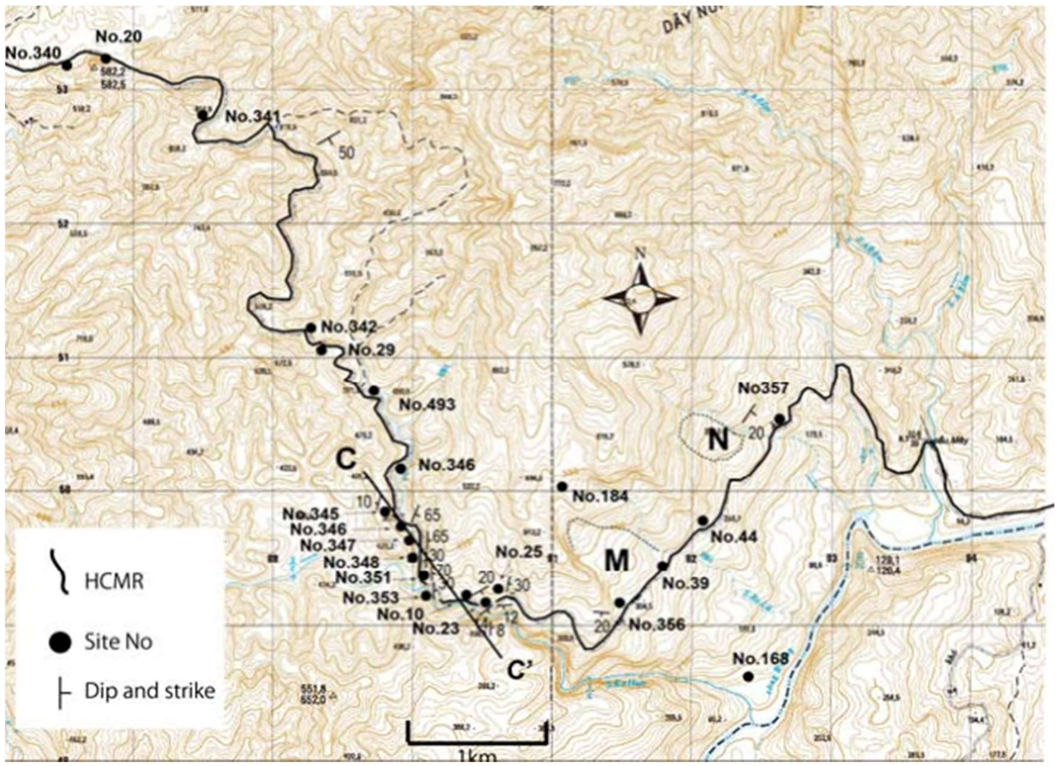


Fig. 4.12 The map of Mesozoic sedimentary rocks survey points

The landslide effects are apparent on the road and retaining walls between No. 356 and No. 44 in Fig. 12. Especially since 2011, on the 400-m stretch from No. 356, new cracks of 5–10 cm have appeared each year after heavy rains (Fig 4.16). The surrounding area corresponds to cuesta landforms with the homoclinic structure. Landslides of both length and width of more than 1 km can be confirmed from satellite photos.

The side of other landslide using a coal seam as the sliding surface is apparent in the outcrop at an old quarry about 1 km east of this point (Fig 4.17). Therefore, this large-scale landslide is identified as a translational landslide with a coal seam as the sliding surface, similar to four slides noted between No. 10 to No. 25.

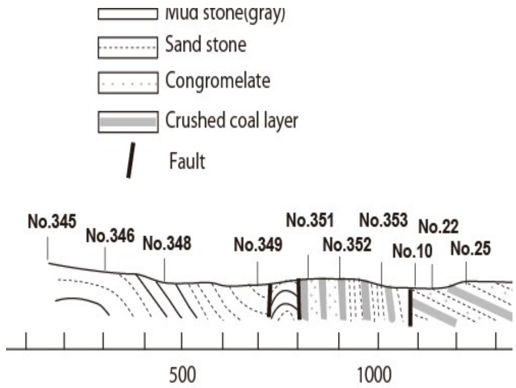


Fig. 4.13 Schematic C-C' cross-section of Fig.12

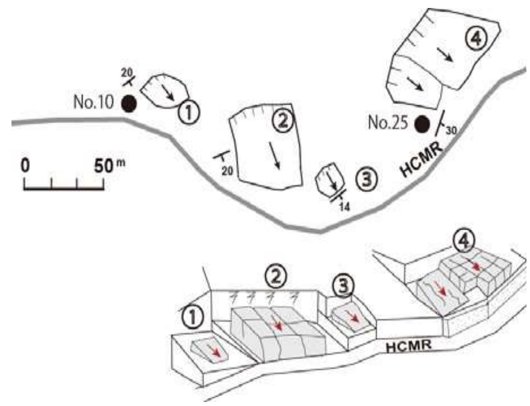


Fig. 4.14 Translational rockslide around No.10-25

Fig. 4.15 Landslides in coal seams (No.10 left, No.25 right)

Fig. 4.16 Effects of landslides on a 400m Stretch of the road near No.356

Fig. 4.17 Translational rock slide and Slide surface of coal bed –No.357

4.6 Discussions

The changes in the landslides of movement types in the study area depend on geology, geological structure, and weathering of bedrock characterized by bedding, schistosity joints, and faults in the geological structures. Consequently, landslides are classifiable into translational rockslides, translational shallow debris slides, translational wedge type slides, rotational slides, gully type slides and flows, and rock falls.

In Paleozoic sedimentary rocks in the northern part of the study area, landslides of common types are rotational slides in the weathered mudstone, sandstone, and shale, and translational shallow debris slides in weathered surface areas with bedrock thickness of less than 1 m.

In Paleozoic metamorphic rocks in the central region, gully type slides and flows in weathered red schist, and translational shallow debris slides in less weathered areas commonly occur.

Most landslides in Mesozoic sedimentary rocks in the south are translational rockslides involving coal seams in sandstone and conglomerate as the sliding surface. The occurrence of these landslides is associated with cuesta landforms of the homoclinic structure, and with fracturing of the geological layers because of folding.

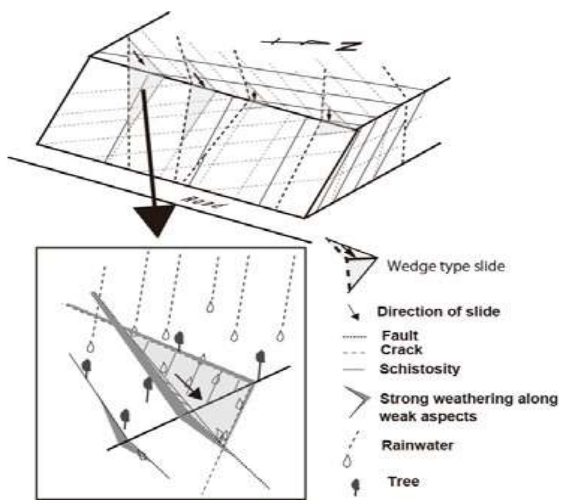


Fig. 4.18 Schematic diagrams of cracks and faults with wedge type slides in Metamorphic rocks

Gully type slides and flows, and translational wedge type slides occurring in metamorphic rocks have fundamentally the same occurrence mechanism. Translational wedge type slides have aside scarp or a base that matches a weak surface such as schistosity, faults, and joints (Fig 4.18).

Gully type slides and flows occur in the areas of advanced weathering such as ridges and steep slopes. However, when the shape of the origin is investigated, many translational wedge type slide shapes can be confirmed. Bedrock around Prao is heavily weathered and brown; many landslides have occurred there. Fresh bedrock surfaces are visible in rivers at the bottom of the slope. Therefore, the weathered portion thickness is 10–20 m. This brown soil has high clay content. Its permeability is regarded as low. Weathering can reach deeply into areas such as this as rainwater percolates along faults, joints, and schistosity (Fig 4.18). Therefore, in areas with less weathering, translational wedge type slides are common. In contrast, gully type slides and flows are common in weathered areas. A large-scale landslide in schist noted at No. 80 can be considered a complex of multiple wedge type slides (Fig 4.19). When these landslides occur in a row, or as a complex, the movement will resemble a large-scale rotational slide.

Fig. 4.19 A large-scale landslide occurred as a complex of wedge type slides (No.80)

Landslides in Mesozoic sedimentary rocks use the fractured coal seam within sandstone and conglomerate. Kaolinite and illite were identified in the X-ray diffraction results of clay in the sliding surface at No.25 in Fig. 12 (Fig 4.20). A report by Trung et al. (2014) similarly identified kaolinite and illite in sliding surfaces in the northern Vietnam region of Ha Long where coal seams make up the sliding surfaces.

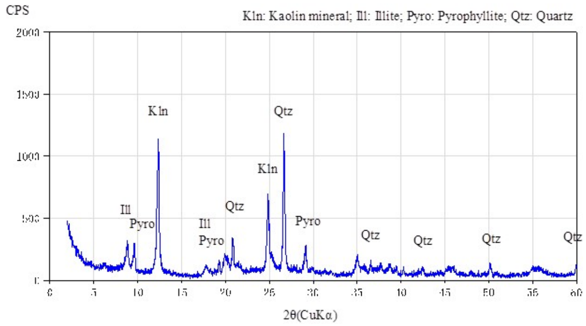


Fig. 4.20 X-ray diffraction results of the sliding surface in the coal seam

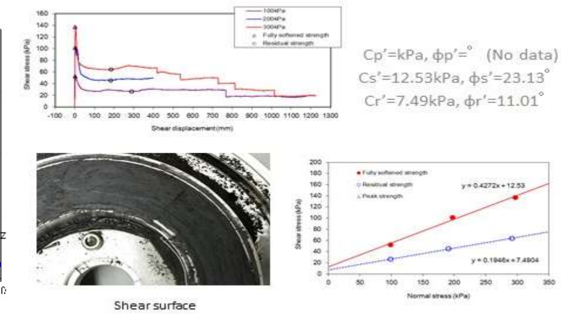


Fig. 4.21 Results of ring shear test on sliding surfaces in the coal seam

Residual strength Φ' r from ring shear tests was 11 degree, resembling the value obtained for tertiary landslides in Japan (Fig. 4.21).

	UniaXial compressive strength N/mm^2	
site No	No.42	No.10
conglomerate	373.9	
sandstone	227.9	84.7
Coal	68.5	-
Crushed coal	13.5	unmeasurable

Fig. 4.22 Uni-axial compressive strength conversion by the Schmidt hammer

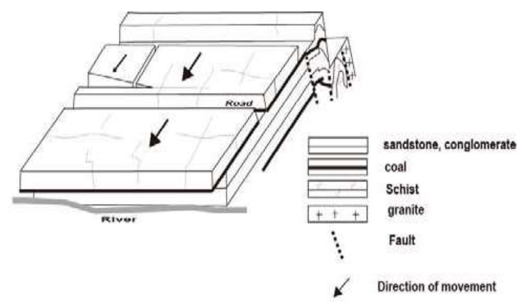


Fig. 4.23 Large scale translational rock slide in Mesozoic sedimentary area

The uni-axial compressive strengths of sandstone, conglomerate, and coal seams were converted from results of the Schmidt hammer test. Results show a notably low value for the coal (Fig. 4.22). Cracks (joints) occurring at regular intervals on sandstone and conglomerates and small faults in coal seams can be regarded as deformation structures accompanying folding of sandstone and conglomerate with a brittle competent layer or muddy coal seam as the ductile incompetent layer. In other words, periodic disturbances probably continue during heavy rainfalls because of crack development in sandstone and conglomerate from fold structures, fracturing and argillization of coal seams, and percolation of rainwater into these cracks (Fig. 4.23). In addition, rock falls noted in hard bedrocks such as Paleozoic shale and Mesozoic sedimentary rocks are constrained by beddings and joints and in where creep is present within the area of Hornfels distribution.

4.7 Conclusions

Approximately 180 landslides confirmed along a 150-km stretch of the HCMR in the Central of Vietnam were examined. The results are described below.

In this study area, many landslides occur as a road hazard. These landslides have a movement type characteristic of the geology and weathering of the area. Therefore, landslides in this study area were classified into translational rock slides, translational shallow debris slides, translational wedge type slides, rotational slides, gully type slides and flows, and rock falls.

The occurrence of these landslides is related closely to the geology of the area and weathering. In other words, in Paleozoic sedimentary rocks in the northern part of the study area, rotational slides are common in the weathered area. Translational shallow debris slides are common in the weakly weathered area. Gully type slides and flows are most common in metamorphic rocks in the central part of the study area, concentrated in the strongly weathered areas. In areas with weak weathering, translational shallow debris slide is more common. Most landslides in Mesozoic sedimentary rocks in the south are translational rock slides using coal seams as the sliding surface.

Weathering of metamorphic rocks in the central area is advanced deeper because of penetration of rainwater through weak surfaces such as schistosity and joints, and also because of the development of faults. In the study area, translational wedge type slides develop using the intersection of these weak surfaces as the sliding surface.

With increased weathering, this develops to gully type slides and flows. Landslides in sedimentary rocks of the southern part of the study area are controlled by cracks in the bedrock. Coal seams in sandstone and conglomerate acting as the sliding surface are fractured. They have many small faults. These small faults in the coal seams have different orientations from the fault direction and the dip of the whole study area. Therefore, it is regarded as deformation structures in sandstone and conglomerate as a brittle competent layer and muddy coal seams as a ductile incompetent layer associated with folding structures.

Mesozoic mud stone, sandstone, and conglomerate (excluding coal seams), and Paleozoic schist and granitic rock are truncated by faults with the strike of N–S to NW–SE and a high-angle dip of 70–90°. Consequently, faults likely occurred post-Mesozoic because of uplifting of granite. Moreover, the scrape directions for several fault surfaces show low angle bedrock displacement in the range of 30°–50°.

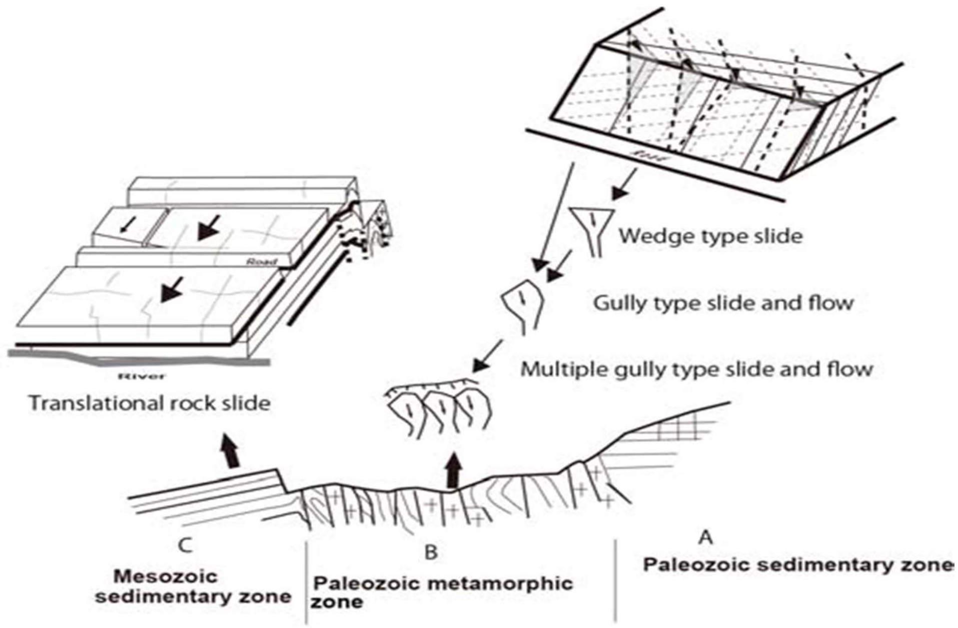


Fig. 4.24 Geology and landslide types of the HCMR

The results presented above showed that landslides in the study area have various movement types. Widely various geology and geological structures lead to these various movement types, such as cracks forming in association with post-Mesozoic folds and faults, fracturing of coal seams associated with fold structures, weathering of bedrock caused by percolation of rainwater along cracks, and development of cuesta landforms (Fig 4.24).

This result is an important indicator for elucidation of the landslide generating mechanism and landslide risk assessment.

CHAPTER 5 –LANDSLIDE SUSCEPTIBILITY MAPPING ALONG HCMR IN THE CENTRAL OF VIETNAM: AHP APPROACH APPLIED TO A HUMID TROPICAL REGION (Tien, D. V. et al., 2016)

5.1 Introduction of Natural Characteristics of the Study Area

In Vietnam, mountainous terrain accounts for up to 3/4 of all territory. The country is situated on a dangerous cleavage terrain affected by the Earth crust's powerful tectonics. Bordered by the Pacific Ocean, it is also influenced by the monsoon climate, with high average annual rainfall, and complex geological structures with jagged geomorphology. Landslides are the most important "natural hazard", especially in northern and central Vietnam.

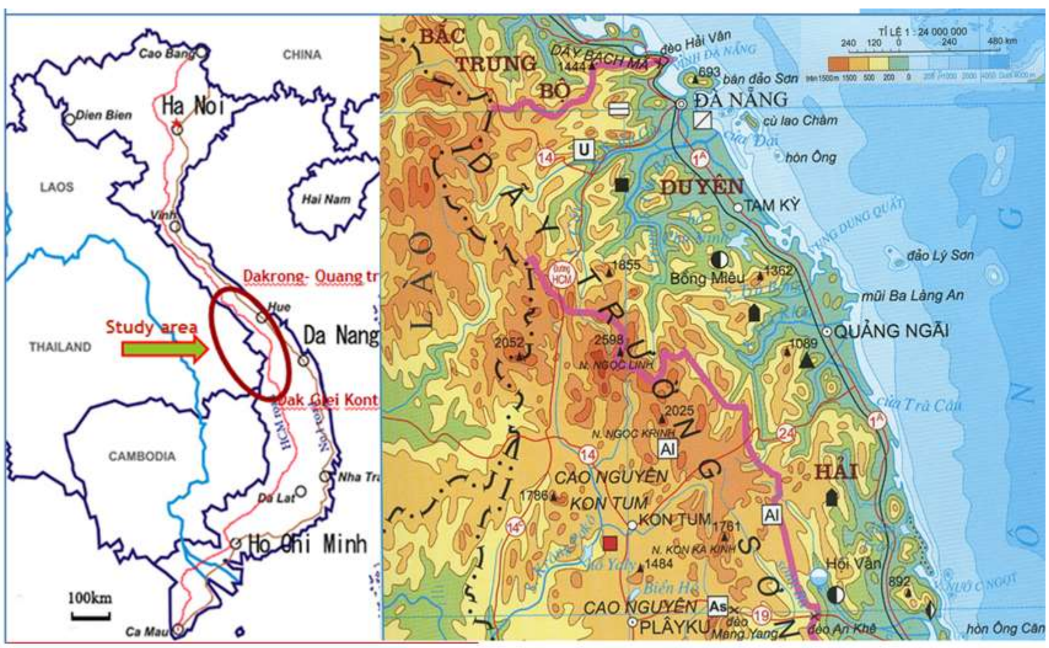


Fig. 5.1 Location and natural feature of the study area

The study area is a zone that includes HCMR corridors in the the Central of Vietnam, where the landslides are regarded as frequent and dangerous phenomena causing widespread economic damage to the transport sector and local residents. The strategic route of HCM is nearly 1800 km long from Hoa Lac (Hanoi) to HCM City. This route is a part of the North–South expressway master plan approved by the Vietnamese government. The target of the study section is approximately 300 km of

HCMR, which begins from the junction with national Highway No. 9 (at the cable stay Bridge Dakrong- Quang Tri Province) to Dong Loc, Dak Glei Kontum Province. In this research, the study area is a zone limited by a distance of 20 km offset to both sides from the center-line of HCMR, extending northwest and southeast between the latitudes of 16° 40'N and 15° 30'N and longitudes of 106° 15'E and 106° 50'E; extends to three provinces of Quang Binh, Hue, and Quang Nam. The study area is presented in Fig5.1.

Regarding topography and landforms, because the geology structure of Truong Son Mountains located along the west side of the study area the terrain was lower from west to east with three typical types: (1) medium to high mountain areas, distributed in the west from the top of the Truong Son range to domain hill bowl area; (2) midlands and narrow delta along the study area; and (3) the coastal areas. The HCMR lies mainly in the medium to high mountain area, located in western Vietnam, close to the Lao border, with average elevation of 700–2000 m. The highest summit reaches 2,598 m (Ngoc Linh Mountain). The terrain surface shows strong cleavage because of erosion, weathering, and tectonic action.

The geomorphology of the Vietnam midlands is generally divided into two regions. Region 1 includes the provinces of Quang Tri and Thua Thien-Hue, except the areas of Bach Ma National Park. Mountains here are concentrated in the northeast southwest, parallel to the coast. The main rivers also follow the water convergence of these mountains. Region 2 includes the area of Bach Ma National Park and of Quang Nam province, which extend west east. The study area spreads along the longitudes and has geomorphologic character of both described regions. The south of the study area corresponds to cuesta landforms with homoclinic structure. Topography and landform of study area is presented in Fig 5.2.

The regional climate of study area is classifiable into three basic climate zones: Quang Tri province – a tropical monsoon climate zone resembling the northern Vietnam climate; Quang Nam province – the southern tropical climate zone; and Hue as the transitional one. They also have similar characters. The average annual temperatures of the study area are 20–28°C, with occasional temperatures of 40°C–41°C in Hue during summer. The average annual precipitation is 2,200 – 2,600 mm, although it can reach 4,000 mm in Bach Ma, Thua Luu Mountains, Quang Nam Province. The storm season extends from the June through November every year. During September and October, the number of tropical storms coming to these provinces is greatest. Tropical temperatures, high humidity, the weathering with very high density of vegetation hide evidence of natural phenomena that took place in the past. Most signs of past slide activity are difficult to observe.

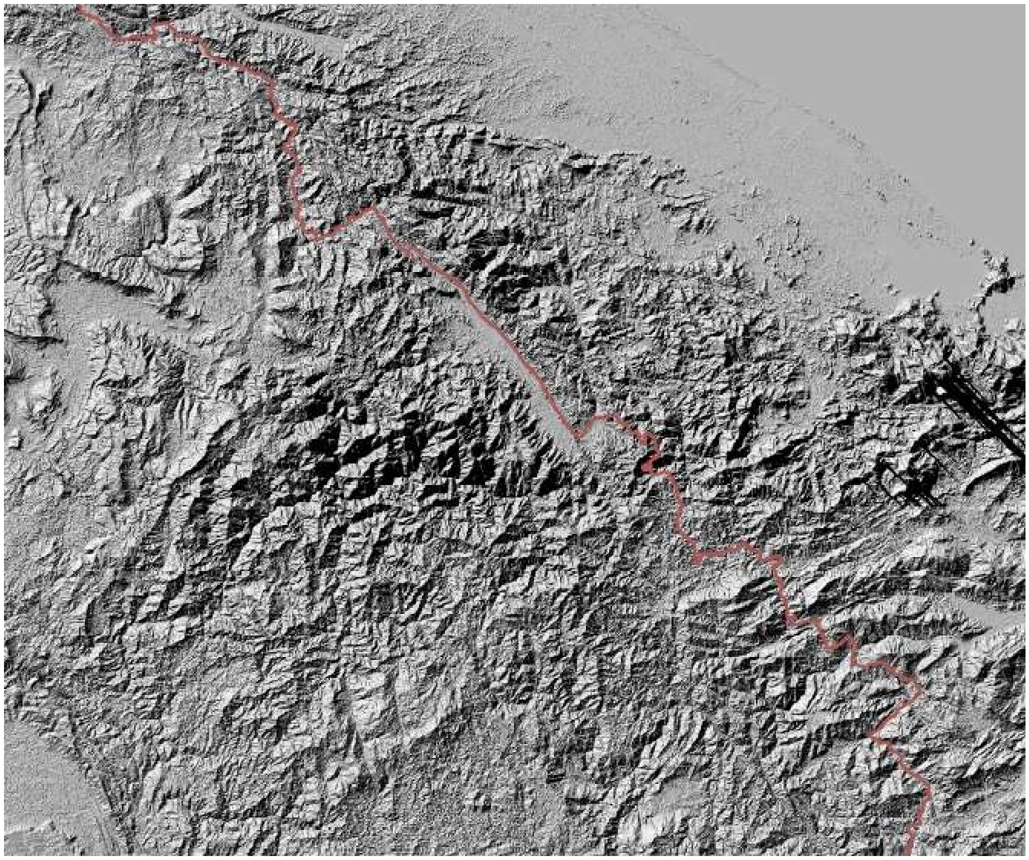


Fig. 5.2 Topography and landform of the study area

Locating on the Truong Son block on geology the structural block map, the geology along the HCMR is dominated by Paleozoic sedimentary rocks (such as limestone, shale, slate, and tuff) in northern areas including A Luoi, Paleozoic metamorphic rocks (such as schist and gneissic granite) in the central areas including Prao, and Mesozoic sedimentary rocks consisting of sandstone with coal seams, mudstone, and conglomerate in the south. Additionally, in some areas, granite is exposed, exhibiting hornfels and gneissic granite on the edges (granite/gneiss). For the degree of weathering, brown to yellow soil is regarded as strong. Soil containing gravel is also strong. Rock with partially open cracks is regarded as weak and fresh bedrock does not weather (Abe, S. , 2014). Rock type contributions of the study are presented in Fig 5. 9.

The study area is located in the the Central of Vietnam, which is an area with extreme climate, affected by heavy rains, high jagged terrain, and complex geological structures, as described. In such natural conditions, landslides are common natural phenomena occurring on this place during the rainy season.

5.2 Landslides Occurring along the HCMR and Data Survey Results

After traffic operations, since 2004, along the HCMR in the study area, many slope failures have occurred. Hereinafter they are described as landslides. According to historical data accumulated through 2013, 604 landslides of different sizes were recorded along the road.

Fig. 5.3 Photographs of landslides, which often occur on the HCMR in Vietnam

A (N15° 48' 10.6", E107° 53' 07.1") Translation, B (N16°' 24' 07.4", E107° 04' 54.1") gully, C (R: N16° 23' 46.5", E107° 05' 59.6") rotational, and D (N15° 53' 36.9", E107° 04' 54.1") rock fall

According to survey data from the Institute of Geology and Minerals (Tran , T. V. and Tien, D. V., 2006), 167 landslides occurred along the HCMR in 2004. After the rainy seasons of 2006 and 2009, the Research Institute of Transport Science and Technology (ITST) conducted numerous investigations of slope failures. The numbers of landslides were recorded respectively as 178 and 248 landslides (Tien, D.V., 2010).

In 2013, with the thin scope of Project Development of Landslide Risk Assessment Technology along Transport Arteries in Vietnam, which was done by ITST and ICL, 15 additional landslides were recorded.

In particular, four sections of this road required special attention because of heavy landslide appearance. They are Section 1 includes Road section on Dak Rong, Ta Rut district, and the 8 km long Peke Pass. Section 2 includes 25 km of two pass sections of A Roang, A Luoi, Thua Thien Hue province. Section 3 includes Adich-Alo Section, Quang Nam province. Section 4 includes Alo-Xaoi Section. Based on data of the investigation, a landslide distribution map was established as basic data for this study. A landslide distribution map of the study area with the four described sections is displayed in Fig 5.4. Most slope failures were cut-slopes of roads that collapsed under the direct impact of rain. Regarding the type of movement, they were divisible into three main categories as slides (32.1%), falls and toppling (55.9%), and flows (11.9%). Typical landslide images are portrayed in Fig 5.3

5.3 Landslide Survey Results and Causative Factors

To ascertain why landslides have occurred so often in this area and to elucidate the main reasons for their appearance, a large site survey of 604 slope failures was done. Experts considered the weights of landslide causative factors. To assess landslide susceptibility, the identification of causative factors, which are classifiable 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. rainfall) usually targets of the study.

Actually, the landslide process depends on many factors such as topography and geomorphology, geology, climate, and human impact. However, necessary factors should be used for a concrete study of this zone, based on relevance, availability and scale of map (Slide, R. C. and Ochiai, H., 2006). Therefore, as objects of analysis for this study, minor and indirect factors were ignored in favor of factors such as elevation, slope angle, land use, rock type, total annual average precipitation, fault density, and distance to the road.

Principles of analyses to evaluate the weight of each factor, which contribute to the sensitiveness of occurred landslides. From survey results, positions of respective landslides were recorded. Six maps of causative factors as described were created from available data, in which each causative factor was divided to different classes. The relation of different classes of each sensitive factor and number of occurred landslides (NOL) and density of occurred landslides (DOL) were studied. Actually, NOL is an important index for consideration because landslides were only recorded along the road, which runs over a certain area of study area, not the entire area. Therefore, a second index represents the landslide number that occurred per unit of area as DOL giving out. Then GIS technology was imported for analyses.

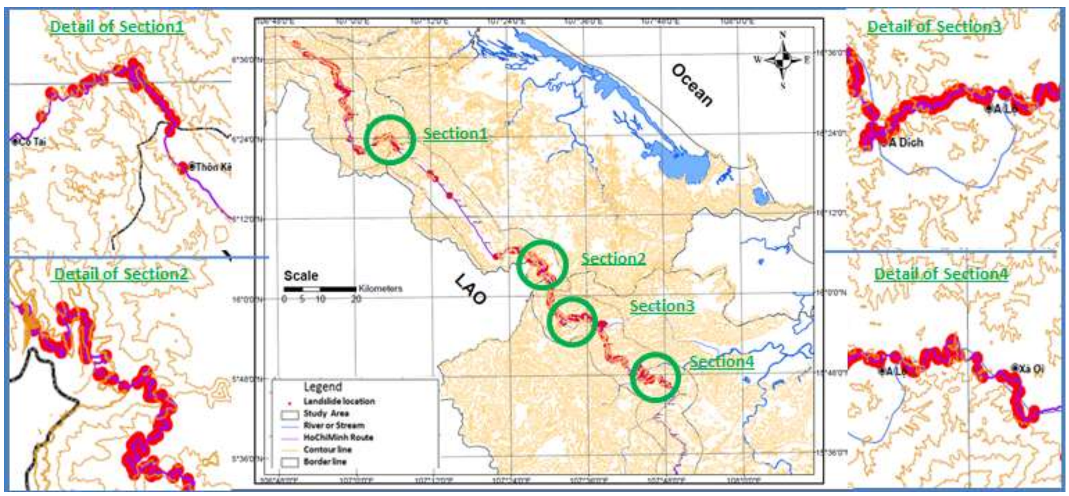


Fig. 5.4 Landslide distribution map of the study area and four severe landslide sections

5.3.1 Natural Slope Angles

Regarding topography, the slope angles, slope type (convex, plannar, concave) and the dynamic processes on the slopes strongly influence the slope stability, particularly on steep terrain, because of the concentration of the surface and sub-surface water. This slope angle is a principal causative or trigger factor. The steeper a slope is the greater risk of land sliding is because of higher shear forces induced by gravity. Therefore, the use of a typical geomorphological factor as a natural slope angle is necessary for the landslide risk assessment

A digital elevation model (DEM) of study area with a resolution of 50 m × 50 m was digitized from the available 1:50,000 scale topographic map. Fig 5.5 shows the digital elevation model of the study area. Based on the digital elevation model, a slope angle map of the entire study area was derived using the slope function of ILWIS 3.0. It is shown in Fig 5.6. A slope angle map of the study area was classified into six different classes groups separately following the classification, which was defined by many researchers of landslides and geomorphology throughout the world as follows: flat-gentle slope (< 3°), fair slope (3–8°), moderate slope (8–15°), fairly moderate slope (15–30°), steep slope (30–45°), and very steep slope (>45°).

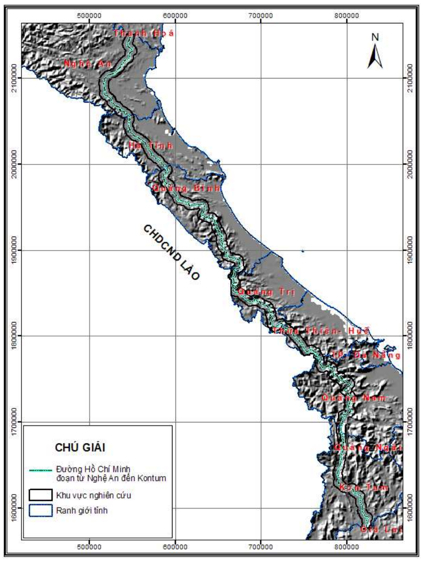


Fig. 5.5 Digital elevation model of the study area

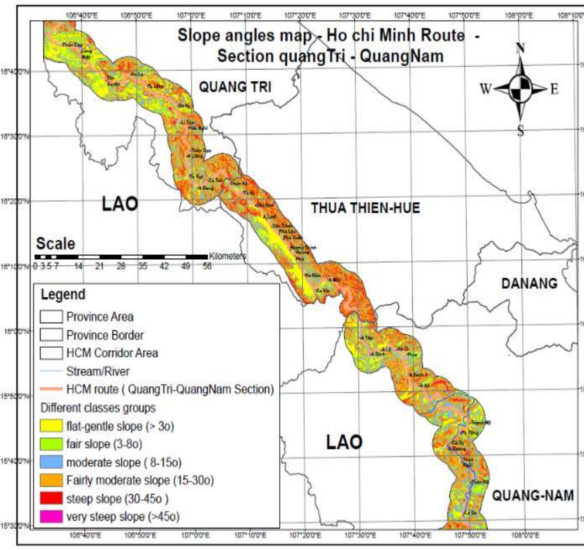


Fig. 5.6 Slope angle map of the study area

Showing zone with flat-gentle slope (< 3°), fair slope (3–8°), moderate slope (8–15°), Fairly moderate slope (15–30°), steep slope (30–45°) and very steep slope (>45°)

Table. 5.1 Analysis Result of NOL and DOL index with Slope Angle classes

Slope Angle classes	NOL	Area (km^2)	DOL
[1] Flat-gentle slope (< 3°),	113	432,422	0.261
[2] Fair slope (3–8°),	82	347,838	0.236
[3] Moderate slope (8–15°)	85	531,828	0.160
[4] Fairly moderate slope (15–30°)	105	236,595	0.444
[5] Steep slope (30–45°)	213	937,005	0.227
[6] Very steep slope (>45°)	7	20,19	0.347

From the locations of slope failures that occurred on different class zones of natural slope angles, we were able to recognize that NOL and DOL increase when the natural slope angle increases. At the natural slope angle as 30–45°, NOL is highest. At the zone of flat-gentle slope angle (> 3°), most landslides are caused by the failure of artificial slopes, which were created from excavation of natural slopes to facilitate road construction. That is an explanation for the quite high NOL index recorded. At a very steep slope angle (>45°) zone, where most road designers prevent road-alignment because of difficulty in stable cutting of the slope, the NOL index is small. Result of the study is present in table 5.1.

5.3.2 Fault Density

The fault density factor represents the shattering of rock. The total fault length in a certain area defines it (usually by 1 km^2). (Vaners, 1984) Concluded that the degree of fracturing and shearing takes an important role in determining slope stability. Fault density is usually considered in landslide assessment.

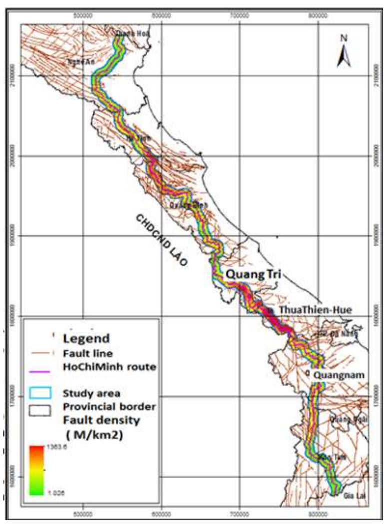


Fig. 5.7 Fracture density map of the study area of HCMR corridor

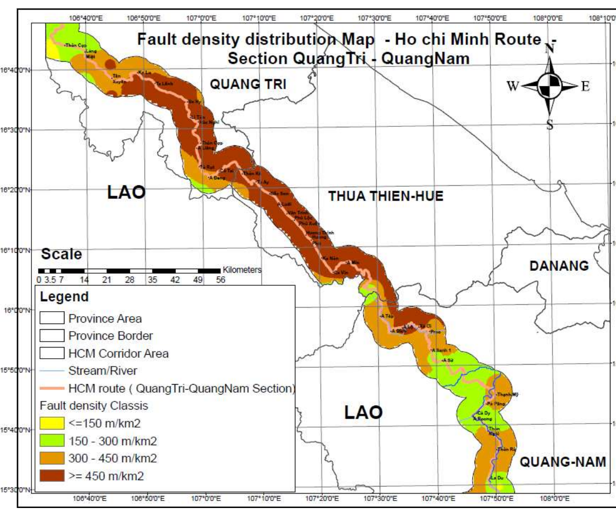


Fig. 5.8 Fault density distribution map of the study area Showing area with<= 150 m/km^2, (150–300) m/km^2, (300–450) m/km^2 and (>= 450) m/km^2

A digital fault density map of the study area was calculated based on taking the total number length of faults per unit area from the faults model of the available 1: 200,000 scale geological map created by the department of geology, Ministry of Natural Resources, published in 2005. In this study, for calculation of the fault density, the method of inverse distance to a Power, Kriging, Minimum curvature (Shepard) from ARCGIS 10.0 is used. A fracture density map of the study area along the HCMR corridor is portrayed in Fig. 5.7. To facilitate the assessment of the relation between fault density and the current state of landslides in the study area, the fault density map was classed into four separate groups as follows: <= 150 m m/ km^2, (150–300) m/ km^2, (300–450) m/ km^2 and (>= 450) m/ km^2. The map of the fault density distribution of the study area is presented in Fig. 5. 8.

The analysis results of value NOL and DOL index belonging to separate fault density class zones is presented in Table 5.2. A high number of fault density or shattering of the rock is associated with large numbers for NOL and DOL.

Table. 5.2 Analysis Results of NOL and DOL index with Fault Density Classes

Fault density classes	NOL	Area (km^2)	DOL
[1] <=150 m/km2	0	25.93	0.000
[2] 150–300 m/km2	125	554.15	0.226
[3] 300–4500 m/km2	169	802.12	0.211
[4] >=450 m/ km2	311	1,122.21	0.277

5.3.3 Geology

Geology is a basic causative factor group for landslide assessment because in many cases of landslide trigger factor are not only high slope anger and precipitation but also geology. It can explain for landslide case took place at very low natural slope angle. The slope instability and regolith material of different types are strongly associated (Sarkar, S. et al. , 1995). Four causative factors of the geology group related to land sliding are usually studied: tectonic structure, crust, engineering geology, and hydro-geological factors (Tran , T. V. and Tien, D. V., 2006). However, this study emphasizes investigation of the relation between the occurrences of landslides and engineering geology.

Regarding engineering geology, the mechanical and mineral chemistry characteristics are closely related to stability of slopes in which shear intensity is a mechanical property that strongly influences the stability of natural and artificial slopes. It has no certain value but it is strongly influenced by the load operations occurring on slopes that are most strongly affected by soil water. The shear intensity of soil is fundamentally represented by a function of the vertical pressure on the sliding surface (σ), the cohesive force (C), and friction angle (φ). The relation among these components of the natural characteristics of the soil has also been examined in many works in the literature and has been specified by different rock types.

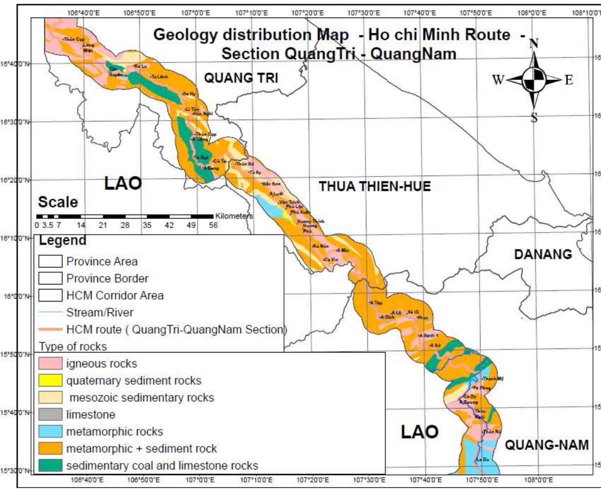


Fig. 5.9 Classification Rock Map of the HCM study area showing seven rock types

[1] Igneous, [2] Quaternary sedimentary, [3] Mesozoic sedimentary, [4] limestone, [5] metamorphic, [6] metamorphic + sedimentary and [7] sedimentary with coal and limestone

Table. 5.3 Analysis Result of NOL and DOL index with Types of rock

Rock type	NOL	Area (km^2)	DOL
[1] Limestone	0	0.00	0.000
[2] Igneous rock	0	519.30	0.000
[3] Mesozoic sedimentary rock	1	245.02	0.004
[4] Sedimentary with coal and limestone rock	21	254.59	0.082
[5] Metamorphic+sedimentary rock	484	1340.02	0.361
[6] Metamorphic rock	91	138.87	0.655
[7] Quaternary sediment rock	8	7.18	1.114

Based on the available geological map scale of 1: 200,000 created by the Department of Geology published in 2005 under the Ministry of Natural Resources, this study compiled diagrams showing the distribution of these rock types, with bedrock and soils grouped according to the source. Accordingly, the geology of entire area of the HCMR corridor from Quang Binh to Kon Tum section was divided into seven rock types: [1] igneous rocks, [2] Quaternary sedimentary rock, [3] Mesozoic sedimentary rock, [4] limestone, [5] metamorphic rock, [6] metamorphic + sedimentary rocks, [7] sedimentary with coal and limestone rock. A diagram of rock type classifications is shown in fig. 5. 9.

Based on NOL and DOL depending on rock type area, we evaluated the sensitivity of each rock type zone to appearance frequency of landslides. Analysis results show sensitivity of each rock type zone from weak to strong, as shown in Table 5.3.

5.3.4 Precipitation

Landslide causative climate factor group includes sunny solar radiation, cloud, rain, air temperature, relative humidity factor took part in sliding process through surface water, infiltration into ground, underground water, as a result, landslide initiation mechanism created and movement occurred. Survey records show that most landslides appeared after rains or storms. Precipitation played a salient role in this causative group factor of climate. For an example, given the same rock type but at different times of a year, the slide probability is completely different because of precipitation. For instance, in study area during the rainy season, the landslides probability is much higher than during the dry season. Landslides occur more frequently during months of high rainfall. In landslide research, the role of precipitation is a major influence on the sliding mechanism. Precipitation is closely associated with landslide initiation because of its influence on runoff and water pressure (So, C.L., 1971). Therefore, the climate factor group and the rain phenomena is subject of the study.

However, many parameters can represent for rain phenomena such as maximum rainfall intensity, total rainfall per day, rainy hours per day, number of raining days of month, or total annual rainfall. For this study, the average annual rainfall was regarded as appropriate factor and represent for temporal and spatial rainfall distribution. It also relates to water infiltration content into the slope surface

Precipitation factor used for this study was the average annual rainfall with long-term observations during 1960–2010. Source data were collected from the map the average annual rainfall, scale 1: 500,000 of center of National Hydrometeorology. The map of average annual rainfall of the long-term study area is presented in Fig 5.10.

However, these precipitation values are continuous values or not split by the group. Therefore, it would be a difficult to evaluate and calculate for landslide susceptibility mapping. In this study, an annual average rainfall map of the year is divided into five groups based on differences in precipitation conditions and climate of the study area as the following (< 2300) m/year, (2300–2600) mm/year, (2600–2900) mm/year, (2900–3200) mm/year and (> 3200) mm/year, is presented in Fig. 5.11.

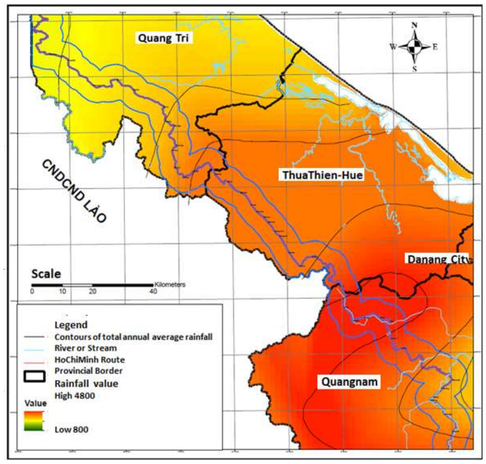


Fig. 5.10 Diagram showing the rainfall distribution of average annual rainfall. Scale 1: 500,000 from the Centre of National Hydrometeorology

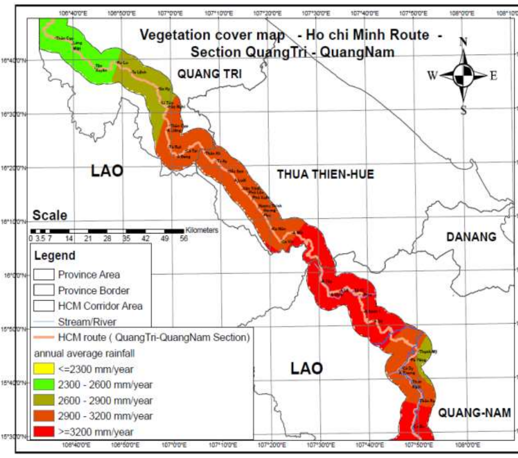


Fig. 5.11 Annual average rainfall map. Showing five classes (<= 2300) m / year, (2300 – 2600) mm / year, (2600 – 2900) mm / year, (2900–3200) mm / year and (> = 3200) mm / year.

Table. 5.4 Analysis Result of NOL and DOL index with total annual average precipitation classes

Total annual average precipitation classes	NOL	Area (km2)	DOL
[1] <2300 mm/year	0	0	0.000
[2] 2300–2600 mm/year	1	338.72	0.003
[3] 2600–2900 mm/ year	74	365.01	0.203
[4] 2900–3200 mm/ year	92	1,049.71	0.088
[5] >3200 mm/ year	438	748.27	0.585

From the values of NOL and DOL, one can readily recognize that the sensitivity of landslides increases concomitantly with the increase of annual average rainfall. The analysis result of the relation between different precipitation zones and NOL and DOL is presented in Table 5.4.

5.3.5 Land Usage

In the study area, the human effects on landslide processes are diverse, such as deforestation, road construction, and agriculture activities; all of them affects slope stability. However, because of limited ability to investigate and evaluate the causes of all human activities affecting landslides in this study, the author emphasizes the impact of changing vegetation cover and road construction in raising the risk of catastrophic landslides.

Poor farming practices and illegal forest clearing have markedly changed the function of vegetative cover in the study area. Land use, especially vegetation cover, augments slope stability by removing soil moisture through evapotranspiration, and by providing root cohesion to the soil (Greenway, 1987).

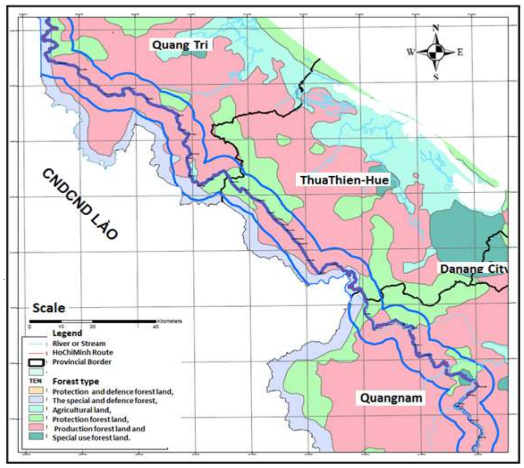


Fig. 5.12 Vegetation cover map of Centre of Vietnam (1:500,000). Created by the Ministry of Agriculture and Rural Development; published in 2010

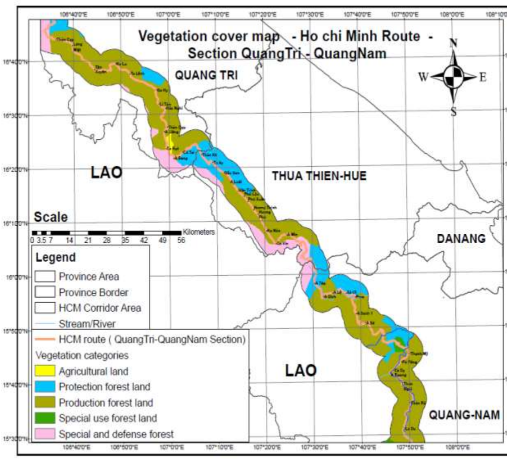


Fig. 5.13 Vegetation cover map of study area

Table. 5.5 Analysis results of NOL and DOL index with land use classes

Land use class	NOL	Area (km2)	DOL
[1] Special use forestland.	6	72.48	0.083
[2] Agricultural land	2	14.05	0.142
[3] Productive forest land	322	1,700.00	0.189
[4] Protected forest land	126	458.95	0.275
[5] Special and defense forest	149	259.06	0.575

Based on a 1 : 500,000 scale vegetation cover map of the Central of Vietnam published by the Ministry of Agriculture and Rural Development in 2010, which classified carpet vegetation into five categories as Defense and special forests, Protected forest land, Special use forest land, Productive forest land, Agricultural land, a vegetation coverage map was extracted for research. This map is presented in Fig.

5.12. The number of landslides for each forest type was analyzed. Extraction of vegetation cover map of study area is presented in Fig. 5.13. The landslide susceptibility rate of vegetation categories zone was evaluated base on NOL and DOL. Table 5.5 presents the results.

5.3.6 Distance to the Road

Regarding road construction activity in mountainous areas, cutting and excavating of natural slopes is the main and common activity. Survey results show that 100% of investigated landslide sites were affected by these activities. The most of landslide phenomena had characteristics of shallow landslides, mainly related to the terrain surface, which was strongly weathered. The direction of geological slope layers exhibits the same direction with the cutting slope of the road. A slip surface usually appears at the position of the geological interface or between different weathering layers. In such cases, the slip surface usually has a non-large radius.

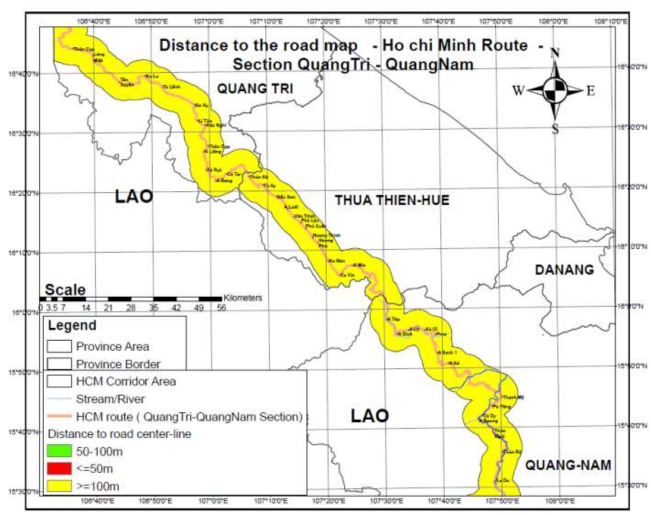


Fig. 5.14 Distance road map

The toe of the rupture surface usually ended up at the middle or end of the cutting slope of the road embankment. However, a few slip surfaces with a large radius, predicted as old landslides, were located under the road embankment. The cutting for road construction disturbed them. For that reason, the sliding movement continued to move with low velocity depending on the water absorption of the sliding block. Numerous cut-slope failures on the HCMR had classification characteristics close with the fall and topple caused by unsuitable cutting slope design and lack of slope protection from water penetration through cracks and strong weathering of the surface layers, with vegetation removed, and the surface partly cut off.

Table. 5.6 Analysis Results of NOL and DOL index Distance to the Road Classification

Distance to the road	NOL	Area (km2)	DOL
[3] >100 m	40	2,443.17	0.016
[2] 50–100 m	44	30.39	1.448
[1] <50 m	521	30.85	16.888

In most landslide cases, the distance from the center of the landslide to the road is regarded as extremely important. To simulate the role of the road construction to landslide risk, the topography map was used. From position of the road, It classifies the distance to the road centerline into three zones of less than 50 m, from 50–100 m and larger than 100 m. A map of different distances from the center road is present in Fig 5.14. The relation between NOL and DOF and difference distance to the road centerline zone was analyzed and recoded. The result is presented in Table 5.6.

5.4 Methodology for Landslide Susceptibility Mapping

Landslide susceptibility of a slope depends many causative factors. For quantitative analysis, exactly the sensitiveness of each causative factor to landslide is difficult. There are some mathematical approach usually use for this evaluation such as the analytic hierarchy process (AHP), fuzzy theory application or the combination of them. AHP is a decision-aiding tool that can facilitate multi-criteria decision. However, the result of decision for landslide susceptibility is based on experience of experts regarding causative factors. Fuzzy theory application is other one that can help to give out the landslide susceptibility naturally with certain confidence value. In some research, the combination of these methods have been applied for evaluation.

For this research, from the landslide survey result and the analysis of the occurred landslide distribution (by parameters NOL and DOL) the relationship of appearance of occurred landslide and causative factors, which were divided in to many classes, was statistical. Landslide susceptibility map can develop from causative factor map with certain weight/ index of relative classes.

The landslide susceptibility index based on the AHP approach is calculated based on a weighted linear combination of causative factor and classes within causative factor as (Voogd 1983).

$$\text{LSI} = \sum_{j=1}^{N} W_j \, w_{ij} \qquad (1)$$

In which :

LSI stands for the landslide susceptibility index,

Wj denotes the weight values of causative factor j.

wij represents the weight value of class i in causative factor j,

N signifies the number of causative factors.

Weights Wj and wij are quantitatively determined by pair wise comparisons and eigenvalues calculations (Saaty, T. L., 1997). The Wj values are obtained as the normalized principal eigenvector of the matrix that portrays the preferences between different causative factors. The wij values are normalized principal eigenvectors of the matrix that portrays the preferences between the classes of a causative factor

Table. 5.7 Scale of preference between two parameters in AHP

Scale	Degree of preference	Explanation
1	Equally	Two activities contribute equally to the objective
3	Moderately	Experience and judgment slightly favor one activity over another moderately
6	Strongly	Experience and strongly favor one activity over another
7	Very strongly	An activity is strongly favored over another and its dominance is shown in practice
9	Extremely	Evidence of favoring one activity over another is of the highest degree possible of an affirmation
2, 4,6,8	Intermediate	Used to represent compromises between the preference in weights 1, 3, 5, 7 and 9
Reciprocals	Opposites	Used for inverse comparison

Table 5.7 presents the matrices are obtained by assigning pair wise preference scales among parameters (it means factors or classes within a factor), (Saaty 2000).The ability to evaluate the consistency of preference ratings. As a measure of consistency, a consistency index CI is defined as

$$\text{CI} = \frac{\gamma_{\max} - n}{n-1} \qquad (2)$$

Therein, CI is consistency index; γmax is the largest eigenvalue of a preference matrix and nits size. Consistency ratio CR as shown below.

$$CR = \frac{CI}{RI} \text{ X } 100\% \quad (3)$$

Therein, RI random consistency index

If the value of the consistency ratio is greater than 10%, then the subjective judgment in the pair-wire comparison between parameters is inconsistent. It must be revised.

The process of landslide depends on many factors. They is divided into four groups: topography-geomorphology, geology, hydrology and artificial actions. However, there are six causative factors are considered in this research. Each factor is divided into classes respective with analysis landslide susceptibility of appearance, which presented in sections 5.3.1 to 5.3.6. Scale of preference value between two parameters arranges from 1 to 9, which is decided based on experience and statistical results. Landslide susceptibility map creation and discussion.

5.5.1 Selection of Parameter Scale and Discussions

According to Table 5.8, the level of the importance of 6 element cause factors are rated respectively on a tapered scale sliding: slope angle, total annual average precipitation, land use, rock type, distance to road, and fault density. Pairwise comparison work was conducted similarly to the information layers in each element causes of landslide disasters. The paired comparison matrix is the basis for assigning weights Wij for the different layers of information in accordance with the values of eigenvector in each matrix (see Table 5.8).

Table 8 presents a pairwise comparison matrix of the causative factors. The first column of the matrix compares the Fault density with other factors that is regarded as more important. The slope angle is regarded as the most important. The second column compares distance to the road with the remaining factors, which are regarded as more important except for fault density, and so on. The similar principle was done to comparison matrix for parameters as slope angle, land use, rock type, total annual average precipitation, fault density, and distance to road. They were presented in sub - Table 1-6.

Table 5.8 (refer to sub-Table1 for topographic slope angle) shows that the higher the slope angle is, the greater its influence on landslide we can get. Evaluation results of pairwise comparison show that the value weighted eigenvector increases with larger slope angle groups. Similar to the total average annual precipitation, the groups of precipitation have higher values that are conducive to landslides (refer to sub-Table 4 for total annual average precipitation). Weight values for the group precipitation as <2300 mm / year, from (2300–2600) mm / year, from (2600–2900) mm / year, (2900–3200) mm / year and >= 3200 mm / year increase respectively as 0.0333, 0.0633, 0.129, 0.2615, and 0.5128.

Weights for the group of fault density also increase with increasing fault density value of the group, as shown in the ninth column of the table values eigenvector (refer to sub-Table 5 for fault density).

The impact of human on landslide processes through cutting road slopes are represented by the distance to roads. The postion is closer to roads, the risk of landslides is higher (refer to sub-Table 6 for distance to the road). The values eigenvector of the distance to the road is less than 50m is highest.

Regarding land use, except the eigenvector of special use forestland increases anomaly because of human activities, others increase from for agricultural land to for special and defense forest (refer to sub-Table 2 for land use).

For different rock types, limestone and igneous rocks are less favorable for landslide occurrence. Mesozoic sedimentary rock and Sedimentary with coal limestone rock, show respectively increasing sensitivity to landslides. At the zone of metamorphic+ sedimentary rocks and metamorphic rocks, landslides mainly occur. Quaternary sediment rock was found to be the most sensitive to landslides. Sub-table 3 shows the weighted values of these different rock types.

Table 5.8 shows that the CR values of causative factors are consistently less than 0.1 that indicates the evaluation followed principles of consistency and conformity.

The attribute field Wig was created and assigned to a corresponding column of attributes as described in Table 5.8. The values wj and wij are calculated in Table 5.8, using the function "weighted sum" in ArcGIS software to implement equation (1) for the risk index landslide hazard maps, the landslide susceptibility map of the study area, along corridor HCMR from QuangTri to Kontum was established.

The landslide susceptibility mapping was thereby created. The landslide susceptibility zonation map shows four landslide susceptibility classes, i.e., low, moderate, high and very high susceptibility. The map was derived from the inventory map, with observations from 2004–2013.

Table. 5.8 Pairwise comparison matrix and normalized principal eigenvector for landslide causative factors and for the classes within each factor, as required for applying the AHP method

Causative Factors	[1]	[2]	[3]	[4]	[5]	[6]	[7]	Eigenvectors
[1] Fault density	1							0.0287
[2] Distance to the road	2	1						0.0400
[3] Rock type	5	3	1					0.0752
[4] Land use	7	5	3	1				0.1292
[5] Precipitation	8	7	4	3	1			0.2875
[6] Slope angle	9	9	5	4	2	1		0.4395
CR = 0.0578								
Sub-Table1-Slope angle								
[1] Flat-gentle slope (> 3°)	1							0.0287
[2] Fair slope (3–8°)	2	1						0.040
[3] Moderate slope (8–15°)	5	3	1					0.0752
[4] Fairly moderate slope (15–30°)	7	5	3	1				0.1292
[5] Steep slope (30–45°)	8	7	4	3	1			0.2875
[6] Very steep slope (>45°)	9	9	5	4	2	1		0.4395
CR = 0.0578								
Sub-Table 2-Land use								
[1] Special use forestland	1							0.3192
[2] Agricultural land	2	1						0.0888
[3] Production forest land	3	2	1					0.1759
[4] Protection forest land	5	4	3	1				0.2731
[5] Special and defense forest	9	7	6	5	1			0.4303
CR = 0.0488								
Sub-Table 3-Rock type								
[1] Limestone	1							0.0238
[2] Igneous rocks	3	1						0.0452
[3] Mesozoic sedimentary rock	3	1	1					0.0452
[4] Sedimentary with coal and limestone rock.	5	3	3	1				0.0955
[5] Metamorphic+sedimentary	7	5	5	3	1			0.1962

Causative Factors	[1]	[2]	[3]	[4]	[5]	[6]	[7]	Eigenvectors
rocks								
[6] Metamorphic rocks	7	5	5	3	1	1		0.1962
[7] Quaternary sediment rock	9	7	7	5	3	3	1	0.3979
CR =0.0474								
Sub- Table 4-Total annual average precipitation								
[1] <2300 mm/year	1							0.0333
[2] 2300–2600 mm/year	3	1						0.0633
[3] 2600–2900 mm/ year	5	3	1					0.129
[4] 2900–3200 mm/ year	7	5	3	1				0.2615
[5] >3200 mm/ year	9	7	5	3	1			0.5128
CR =0.0593								
Sub-Table 5-Fault density								
[1] <=150 m/km^2	1							0.0438
[2] 150–300 m/km^2	4	1						0.0885
[3] 300–4500 m/km^2	7	4	1					0.2431
[4] >=450 m/km^2	9	6	3	1				0.6246
CR =0.060								
Sub-Table 6-Distance to the road								
[3] >=100m	1							0.1095
[2] 50–100m	3	1						0.309
[1] <= 50m	5	3	1					0.8516
CR =0.0018								

5.5.2 Mapping Accuracy

According to the study results of the landslide susceptibility map of the study area along corridor HCMR from QuangTri to Kontum and with the division of the landslide index of Galang method applied. This method was introduced from 2004, with landslide susceptibility divided into four classes from low to very high landslide sensitivity. The number of landslide occurred in lower is a half of higher zone. Overlapping of the landslide distribution map and landslide susceptibility map showed that 26, 80, 255, and 244 landslides in all of 604 recorded landslides were respectively located in low, average, high, and very high susceptibility areas for landslides.

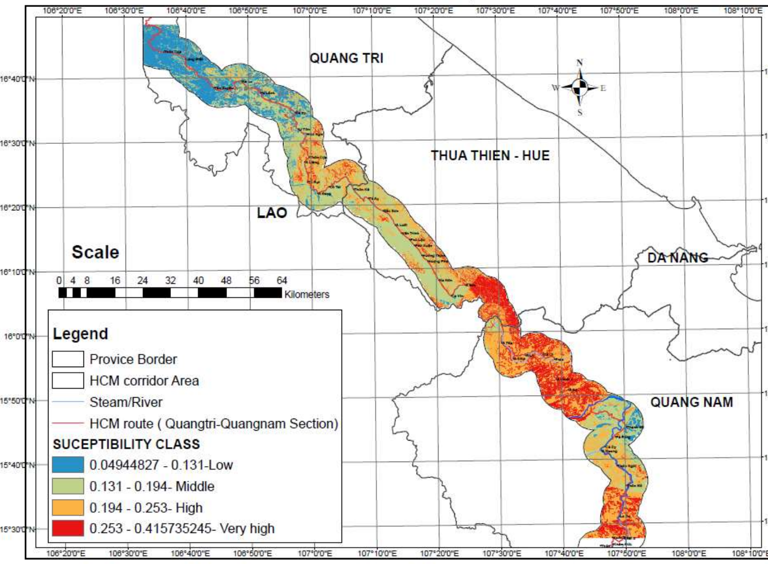


Fig. 5.15 Landslide susceptibility map of the study area, along HCM from Quang Tri to Kontum

The landslide susceptibility map of the study area, along HCM from Quang Tri to Kontum is presented in Fig 5.15. Therefore, 40.40% of the landslides were in the very high susceptibility areas; 42.22% of the landslides occurred in high susceptibility areas; 13.25% of the landslides occurred in middle susceptibility areas; only 4.14% of landslides occurred in low susceptibility areas. Specifically regarding high and very high susceptibility areas, 82.66% all landslides occurred there.

5.5.3 Limitations

Landslides in this study were slope failures mainly located along a road. Positions of slope failures were recorded as points measured from an intersection between the landslide boundary and the road. Therefore, landslides spatial arrangements were only distributions along the road. The susceptibility map scale was large, as 1:500,000, so the areas and micro-features of respective landslides were not considered.

In general, three basic methods exist for creating a landslide distribution map: collecting historical data, conducting field surveys, and interpreting aerial photos. However, for this study, the field survey method was applied to create a landslide distribution map. Landslide surveys are related to human capabilities of recognizing them in terms of number, space, and time, all of which introduce error.

For susceptibility mapping, aside from the considered causal factors, i.e., Slope angle, Total annual average precipitation, Land use, Rock type, Distance to road, and Fault density, other sensitive causal factors such as fault depth, distance to water stream, and alignment were not examined because of their poor relevance and lack of available data sources. Although most landslides occurred in high and very high-risk zones, some landslides occurred in other zones, perhaps because of low-probability causes such as slope cutting for road construction.

5.5 Conclusions

Landslides are regarded as a dangerous phenomenon that often occurs in mountainous regions of Vietnam. They directly affect the lives of the people in the region, destroy traffic infrastructure and road systems. The center section of the HCMR is a mountainous road that is heavily influenced by landslides. Therefore, reducing landslide susceptibility for this important corridor is the target of this study.

Landslides have various possible causes with complex mutual relations. Detailed assessments to ascertain the main causes of each landslide are not feasible in most cases. The selection of causative factors for a landslide susceptibility map is usually based on experts' subjective experience. In this study, to analyze landslide manifestation, causative factors were derived: slope angle, rock type, fault density, and distance to the road, land use, and precipitation. Maps for causative factors were created, with causes divided into classes.

From 604 slope failures were found along the HCMR, a landslide distribution was produced. The landslide sensitivity of each class of causative factor maps was calculated and then evaluated by using NOL and DOL statistic values derived from a comparison of the landslide distribution map and causative factor maps using GIS.

An analytical hierarchical process was used to combine these maps for landslide susceptibility mapping. Consequently, based on the inventory map of observed landslide from 2006–2009, a landslide susceptibility zonation map with four landslide susceptibility classes is derived, with low, moderate, high and very high susceptibility for landslides. This map shows that 82.66% of all landslides have occurred in highly and very highly susceptible areas. Although limited by matters of map scale and available data, the landslide susceptibility map of this study for corridor along this road is expected to be useful for landslide mitigation.

CHAPTER 6 – GUIDELINE FOR VULNERABILITY OF LANDSLIDE HAZARD MITIGATION IN HUMID TROPICAL REGIONS

6.1 Targets for Landslide Hazard Vulnerability Management for Humid Tropical Regions

To Landslide hazard vulnerability management for region in order to natural disaster prevention, response and mitigation the author approach is to answer for questions “ What-Where-When-How’’to landslides. Concept and classification of landslide in study area will be discussed for “What” question. Integrated maps for landslide hazard vulnerability for mitigation will present to answer for “Where” question as site prediction. Setting up local regional monitoring and Material testing reference are applied for “When” question as time prediction. The application of research for landslide prevention, response and mitigation plant will discuss for question “How”.

This guideline for Landslide hazard vulnerability management for region is one of 34 of landslide integrated guidelines of landslide risk assessment, which was developed by the cooperation research project ‘’Development of landslide risk assessment technology along transport arteries in Vietnam’’. The integrated guidelines includes 5 parts, covers on (1) Mapping and site prediction, (2) material tests, (3) monitoring,(4) landslide flume experiment, (5) software and simulations. The detail list of landslide-integrated guideline set list is presented in table 6.3 for reference.

6.2 Landslide Types and Moving Mechanism

6.2.1 Landslide Classification in Region and Recognition Signal

Landslide is complicated movement of slope. According to type of movement, it was classified in to seven types as fall, topple, translational slide, rotational slide, lateral spreading, flow and complex by (Varnes, 1978). The classification was updated (presented in table 6.1) and landslide types were classified in to 29 types depending movement and material (Oldrich, H., 2014). In the study area, the landslide classification is carrying base on Varnes’ 1978 classification system. However, most of landslides are classified based on remaining signals after movement, so in some case the classification was non-consensus from researchers.

Table. 6.1 A summary of Vanners' 1978 classification system (Varnes, 1978)

Movement type	Rock	Debris	Earth
Fall	1. Rock fall	2. Debris fall	3. Earth fall
Topple	4. Rock topple	5. Debris topple	6. Earth topple
Rotational sliding	7. Rock slump	8. Debris slump	9. Earth slump
Translational sliding	10. Rock slide	11. Debris slide	12. Earth slide
Lateral spreading	13. Rock spread	-	14. Earth spread
Flow	15. Rock creep	16. Talus flow	21. Dry sand flow
		17. Debris flow	22. Wet sand flow
		18. Debris avalanche	23. Quick clay flow
		19. Solifuction	24. Earth flow
		20. Soil creep	25. Rapid earth flow
			26. Loess flow
Complex	27. Rock slide-debris avalanche	28. Cambering, valley bulging	29. Earth slump - earth flow

In the study area, beside 5 typical classes as rock fall, debris rotational slide, translational rockslide, translational shallow debris slides, gully type slides and flows, which were classified, the following translational wedge type slides was added. Here after, typical landslide types in study area will be discussed for clear understand for classification.

6.2.1.1 Rock fall

A rock fall or rock-fall refers to quantities of rock falling freely from a cliff face. A rock fall is a fragment of rock (a block) detached by sliding, toppling, or falling, that falls along a vertical or sub-vertical cliff, proceeds down slope by bouncing and flying along ballistic trajectories or by rolling on talus or debris slopes," (Varnes, 1978). In the study area, rock-fall was found in some cases, where is in granitic rocks slide as rock falls of granite core stones formed at shallow layers effected by weathering. However, the number of this phenomenon is small. At the site, after cutting natural slope for road construction, the remaining talus, which were step and some cases were nearly vertical created high potential energy for slope failure to continue development. At most those locations, the dip of geological slope layer, which was strong weathering, was reverse with the dip of cutting slope surface of the road. As the result, rock fall occurred. Rocks falling from the cliff may dislodge other rocks and serve to create another mass wasting process. Pictures of Phenomenon of rock fall on HCMR – Quang Nam section is presented in Fig 6.1.

Fig. 6.1 Rockall on HCMR– Quang Nam section - Vietnam

6.2.1.2 Translational Shallow Debris Slides

Landslide in which the sliding surface is located within the soil mantle or weathered bedrock (typically to a depth from few centimeters to some meters) is called a shallow landslide. They usually include debris slides and failures of road cut-slopes. The survey and study records showed that the most landslide phenomenon in study area had character of sallow landslide, largely related to heavy raining fall to the surface of the terrain, which was strong weathering. In the study area landslides occur in sedimentary rocks with bedding and schistosity, weakly converted crystalline schist, and granitic rocks. Landslides move as a translational slide when the beds are gently sloping, and otherwise as a wedge type slide at an intersection with a crack.

Fig. 6.2 (a) Debris Shallow landslide and (b), (c) Translational wedge type slides in HCMR -Hue section-Vietnam

Pictures of Translational type slides in HCMR -Hue section-Vietnam is presented in Fig 6.2.(a) (on left side). Typical slope in study area was discovered with silt and sand as its top soil and bedrock as its bottom soil. During an intense rainstorm, the bedrock will keep the rain trapped in the top soils of silt and sand. As the topsoil becomes saturated and heavy, it can start to slide over the bedrock and become a shallow landslide.

The slip surfaces usually have the same direction of geological slope layers or cutting slope of the road. Slip surface usually appeared at the position of interface geological or different weathering layers. In those cases, slip surface usually shallow and toe of surface of rupture usually ended up at middle or end of the cutting slope of the road talus. Accumulation of landslide was soil or debris greatly influenced by surface water and ground water, moved following stream over the road surface.

6.2.1.3 Translational Wedge Type Slides

Beside typical landslides as shallow, one more type of landslides was found as translational wedge type slides. The translational wedge type slides have characters of translational slide as mentioned. Beside it, moving mass slides has shape in a triangular form. Gully type slides and flows, and translational wedge type slides usually occurs in metamorphic rocks have fundamentally the same occurrence mechanism. These slides have a side scrap or a base that matches a weak surface such as schistosity, faults, and joints. In the study area, it was usually located in the rock with middle weathering. Pictures of Translational wedge type slides in HCMR -Hue section-Vietnam is presented in Fig 6.2 (b), (c); (Right side)

6.2.1.4 Translational Rock Slides

Translational rockslides have the sliding surface mostly deeply located below the maximum rooting depth of trees (typically to depths greater than ten meters). They usually occurred in relation with the geological structure. This type of landslides are potentially occur in a tectonic active region. They tend form along a plane of weakness such as a fault or bedding plane. Some landslide cases, the depth of slip surface is located over hundred meter on deep, with the size is over several square kilometers and usually is considered as deep-seated landslide. In many cases, the organic layers, such as crushed coal bed, black mudstone, black shale, and black schist, act as a slip plane in sedimentary rocks with developed bedding. Some landslides in areas distributed by limestone occur with limestone as a cap rock. A slip plane is formed in the bedding plane of shale as the underlying layer of limestone and the schistosity plane of weakly converted crystalline schist. All landslides have occurred on a large scale as rockslides.

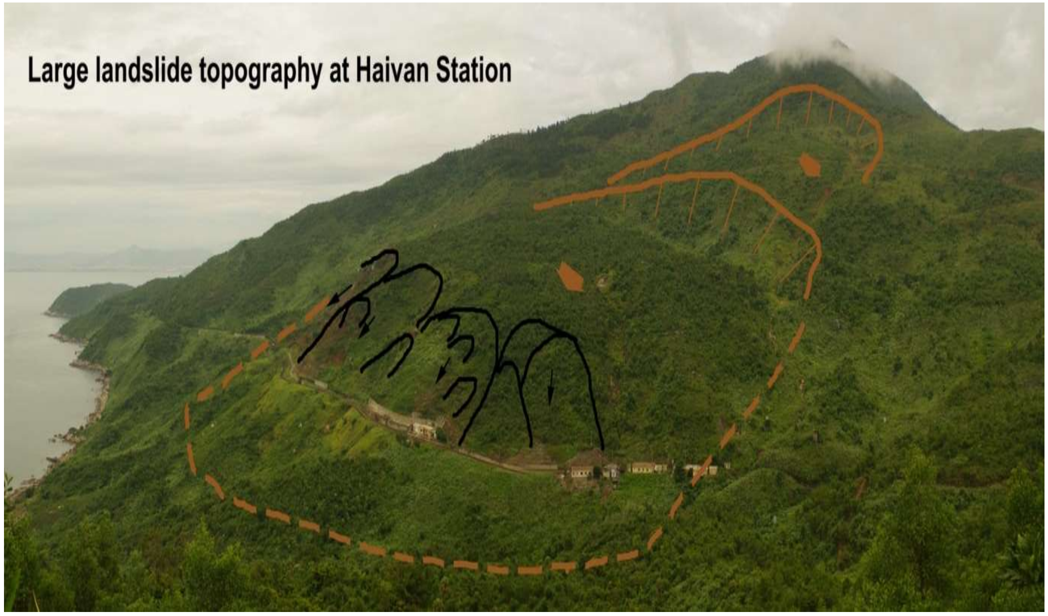


Fig. 6.3 Deep seated Landslide on Hai Van pass - Da Nang –Vietnam

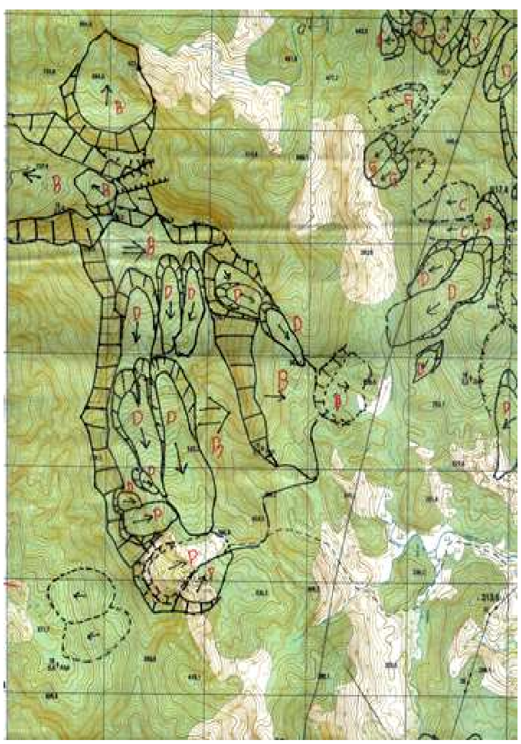


Fig. 6.4-a Photo of Translational rock slide Northwest ward of Thach My town

Fig. 6.4-b Topography of Translational rock slide on Khom9-Kham Duc

A deep seated Landslide original form changes to many minor debris flow inside its landslide body. B means block slide; D means debris flow

In the study area, a number of topographic area of deep-seated landslide distributed. Among of them, the huge landslide distributed at the west point of Kham Duc town, Northwestward of Thach My town and Hai Van pass. The huge landslide distributed at the west point of Khom 9 - Kham Duc My cause by the relationship with the characteristic of ultra-basic rock. Topography map of this Translational rockslide is presented in Fig. 6.4-b. Regarding landslide Topography map, a deep seated landslide original form changes in to many minor debris flows inside its landslide body. B means block slide; D means debris flow. The cause of the one near the Thach My town on HCMR was relation of existence of coal layer between rock layers. The photo of translational rockslide North West ward of Thach My town is presented in Fig. 6.4-a.

Hai Van landslide is special remarkable huge landslide that the real cause is unknown up to now. The land mass of the Hai Van mountains consist with granite. In the granitic area, deeply sheeted landslide is seldom discovered. Pictures of deeply seated Landslide on Hai Van pass - Da Nang - Vietnam is presented in Fig. 6.3.

6.2.1.5 Rotational Debrisslide

Rotational slides occur when a slump block, composed of sediment or rock, slides along a concave-upward slip surface with rotation about an axis parallel to the slope. Rotational movement causes the original surface of the block slipping down, breaking in to many parts with scraps. The top of the slump is rotated backward. In the study area rotational landslides was discovered in deep weathering sedimentary rocks with bedding and schistosity, weakly converted crystalline schist, and granitic rocks. A small number of slip surface with middle to large radius, which was predicted as old landslides, located under the road embankment.

Fig. 6.5-a Photo of landslide body of a rotational landslide in HCMR (Quang Nam section)

Fig. 6.5-b Photo of main scarp of a rotational landslide in HCMR (Quang Binh section)

The sliding movement of the deflection and accumulation zone of deep landslide created cracks and in some cases put up pavement or facilities of road over and they is continues to move with slow velocity depending on the water absorption of the sliding block. Fig. 6.5-a presented main scarp of a rotational landslide and Fig. 6.5-

b presented the body a rotational landslide and in HCMR (Quang Binh section).

6.2.1.6 Gully Type Slides and Debris Flows

Debris flows are geological phenomena in which water-laden masses of soil and fragmented rock rush down mountainsides, funnel into stream channels, entrain objects in their paths, and form thick, muddy deposits on valley floors. Slope material that becomes saturated with water may develop into a debris flow.

Fig. 6.6 Debris Flow and gully on HCMR-Hue Section-Vietnam

In study area, gully type slides and debris flows, by which an arc-shaped sliding mass originating at the upper area of a slope slides down the slope surface, and the morphology resembles an erosional gully. The development of the small gullies is the initial manifestation of the phenomenon due to the movement of soil particles or fragments of weathering surface, which has resource from broken type of geology wedge structure running follow surface water stream. The small gullies develop larger and larger, and created deep gullies on the surface of slopes, and in some cases, they link together and as the result the slopes failure occurred. Pictures of debris flow and gully on HCMR-Hue section-Vietnam is presented in Fig 6.6.

6.2.2 Landslide Moving Mechanism

To landslide, classification types that are discussed above, the mechanism of rock fall is very simple and clear. We concentrated in explanation for Landslides phenomenon include debris flow.

In the case that we studied a unit of soil mass in water on a slope. Under the pressure of ground water rise, the pore water pressure rise respectively. The stress reaches the failure line expressed by equation (1), then the initiation mechanism of sliding starts. There are two factors, that make the pore water pressure rise are ground water rise by heavy rain and earthquake. So the main factor triggered the movement of unit soil mass in water on a slope is the increase of pore-water pressure to make shearing stress equal or larger a shearing stress at failure shear strength of material of each slope.

As discussed above, to contribute for landslide movement there are many causative factors, which are classifiable as dynamic factors (e.g. pore water pressure) and passive factors (e.g. rock structure, land form, slope anger ...).The passive factors take a roll as preparatory factors and nearly unchanged. In the pact, shear strength of material is one of preparatory factors that has small change such as the reduction of value of cohesion (C) depend of content moisture.

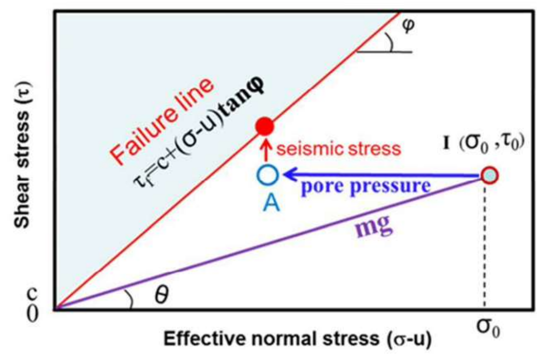


Fig. 6.7 Landslide-initiation mechanism by the combined effect of earthquake and pore -pressure rise (Kyoji, S. and Bin HE, 2012)

Rain is a normal natural phenomenon that we usually meet, especially in rain and storm season. A part of the volume of water from precipitation falls on the slope creates water stream on the surface of slope. The rest penetrates into slope that makes the underground water and increasing the pore water pressure, depending the capacity for discharge of inside contented slope water. Therefore, the change value of pore water pressure depends on slope itself (such as slope gradient, material, etc.) which is stable during process of rain and depend on precipitation as well as interval time between each of each rains. While keeping the water content in slope material if the slope meets the earthquake phenomena, the vibration force will make the pore water pressure increasing in a short time. This will easily trigger rapid slope movement. In other hand, most of soil is not sand absolutely, so value of cohesion (C) of soil exists. Cohesion depend on type of soil as well as its moisture. It makes delay speed of landslide block. This explains for moving phenomenon with slow and middle speed of landslide. The landslide-initiation mechanism by the combined effect of earthquake and pore-pressure rise is presented in Fig. 6.7 for sand material.

However, the study area located in the area that have frequency of earthquake is small. So the main active factor triggered most of landslide in the area is high precipitation. Difference from earthquake action, which brings pore water pressor rise over failure line in very short time, the rain action can make pore water pressor rise very slow, depending water keeping capacity of soil. That can explain for character of the most landslide occurred in Vietnam with middle and slow speed.

6.2.3 The Relationship between Dynamic Factor and Displacement/ Signal for Landslide Recognization

To find the explanation for the signal of landslide movement with the change of pore-water pressure, the relationship of integrated factors triggered of landslide surface of the 1792 Unzen earthquakes in Japan (Fig 6.8) is studied for an example.

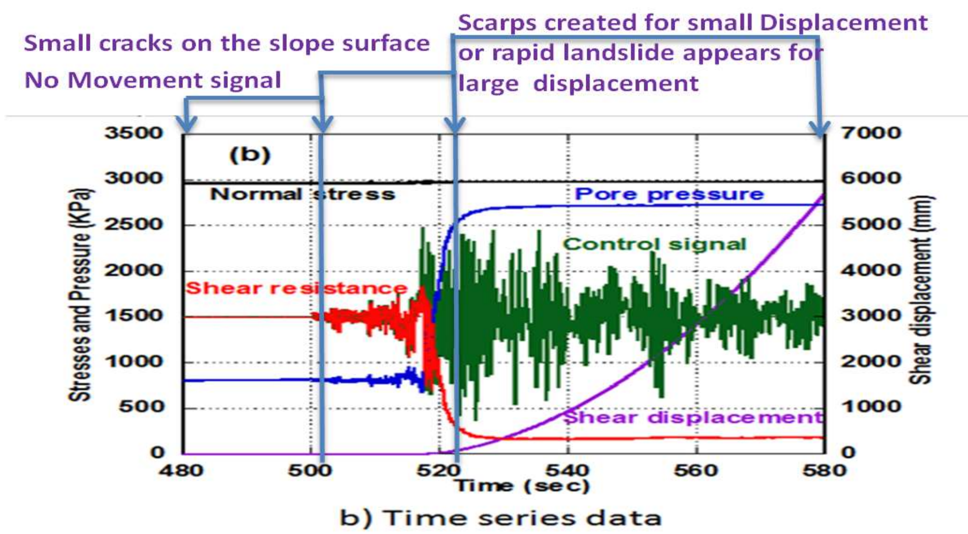


Fig. 6.8 The samples were taken from the landslide surface of the 1792 Unzen earthquakes in Japan

The Fig. 6.8 presented relative parameters of a rapid landslide from initial stage to failure. It will be recognised that on the first zone when the pore water pressure is stable (non change) and shear displacement is zero and It means no signal of landslide is found on the slope. On the second zone of chart, when pore water pressure starts increasing, small shear displacement appears. The landslide starts moving and displacement signal usually found is cracks on the surface of slope. In some cases small main scraps of landslide may be found.

On the third zone , when the pore water pressure increases and gets high value and lasts for a time, shear displacement was increasing. The cracks and small scrap was opened and developing. The signal usually found in large scraps and clear other micro features. The landslide changes in to rapid movement.

However, In fact, except the earthquakes which can make pore water pressure increasing rapidly, the speed of pore water pressure increasing by the rain usually rises slowly, and repeatedly depending water absorption and discharge underground water of the slope. When pore water pressure increases closely to failure line of slope material then reduces, stage of movement is just around the second zone and the first part of third zone. The change of pore pressures repeatedly makes the change speed of movement of moving block. The process of “moving and stop” of slope is considered as reactive landslide. It will be answer for the survey landslide results in study area, in which the most of reactive landslides was found in the area.

To abstract an unstable slope in a landslide, it is important to understand how the topography changes. Landslide processes (from beginning to eternal stop) are not limited to a single pattern. Depending on impact of dynamic factor, a landslide is in stage of moving or pause stage along to the length of slip surface and at last, moving to termination stage. For example, landslide displacement can increase or change the initial micro topography structure by continually expanding. Or, if the landslides stopped state continues for a long time, its micro topography, such as scrap and fissures, undergo moderate sloping, and are gradually lost by impact of other morphology phenomenons. Transitions in landslides from occurrence to termination is presented in Fig 6.9 (Toyohiko, M., 2004). So for forecast of landslide disaster , it is necessary to create the relationship between dynamic factors and displacement / signal of landslide. To study area, dynamic factors here is pore water pressure which is variable from landslide to landslide. However, the indirect factor relating directly to it is rain fall. It should be recorded during landslide moving signal investigation.

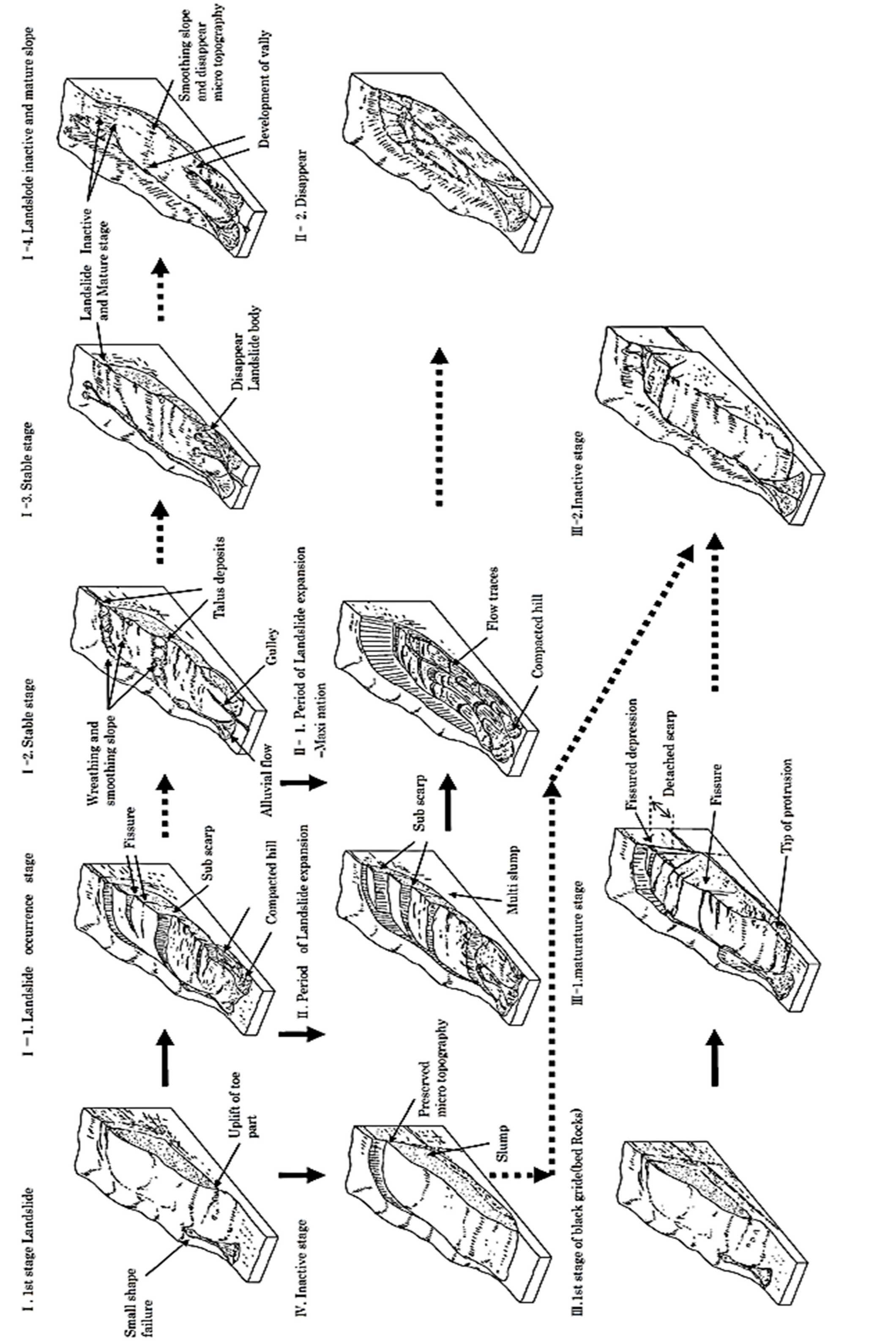


Fig. 6.9 Transitions in landslides from occurrence to termination (Toyohiko, M., 2004)

6.3 Tools for Landslide Management by Region

6.3.1 Basic Data for Landslide Management

6.3.1.1 Landslide Data Collection

Landslide data collection is considered as the basic document (landslide data base) for creation of regional landslide management tools. Landslide data collection is assemblage landslide information, which occurred in each region. With objective of information providing such as landslide classification type, location, boundary and size, including width, height and depth as well as the moving statute of landslide, it should be named or coded for reference.

In general, there are three basic methods commonly used for landslide data collection were employed as field recognizance to investigate landslide occurrences, collection of historic information of landslide and interpretation of landslide occurrences from aerial photographs.

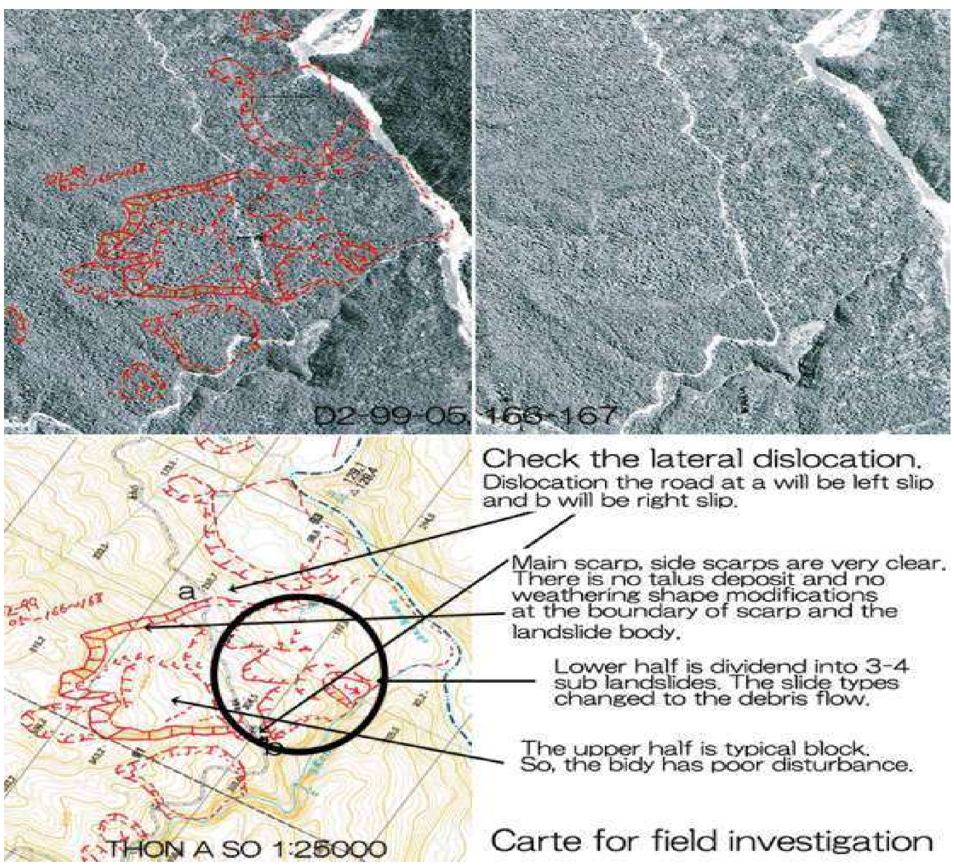


Fig. 6.10 Landslide interpretation of LS No.18 – HCMR – Vietnam

Interpretation of landslide occurrences from aerial photographs is overall method for recognition. Depending on scale and quality of air photo, geomorphology knowledge combining with possible causative factors concerning to each landslide is employed, the information of each landslide could be identified. From results of landslide interpretation, landslide inventory map will be developed. Fig 6.10 presented the landslide interpretation result of LS No. 18 on HCMR, Vietnam as an example of result of landslide from aerial photographs interpretation.

Field recognizance to investigate occurred landslide is direct and detail for landslide data collection. From site survey, information of micro features of landslide could be recorded including:

(i) General information

- Name or code
- Air Photo code reference
- Topographic map reference
- Landslide overview figure, an aerial photo and topographic map interpretation and real site pictures
- Coordination of position
- Date and name of investigator.

(ii) Landslide and landslide topography micro features information (Pattern diagram of landslide topography is presented in Fig 6.11).

-Type of landslide: (landslide, topple, fall, spread, flow….)
- Landslide scale (shape, ratio of height, length, width, estimated depth)
- Landslide topography micro features (scrap zone : degree of dissection, shape of crown; middle zone : dhape of middle; toe zone : shape of toe)
- Landslide activity stage (cracks, opening crack, moving, flowing signals …)

(iii) Causative factors information

- Topography information (slope anger, topographic type , position with beside objects such as road, residential house, stream ..)
- Geomorphology information (surrounding landslide natures, land form, plain view, knick line …)
- Geographical information (type of rock, weathering, dip and strike, special geographical character if any.
- Climate information (recently maximum precipitation …)

Collection of historic information is very important method for landslide data collection. Historical information could suplied usb landslide information regarding historical classification, boundary, micro-feature and movement stage under the types of document such as report, drawing, pictures or map. Landslide inter-phases interpretation is one of example of collection of historic information. Using formed inventory map is one of very useful document for landslide investigation information.

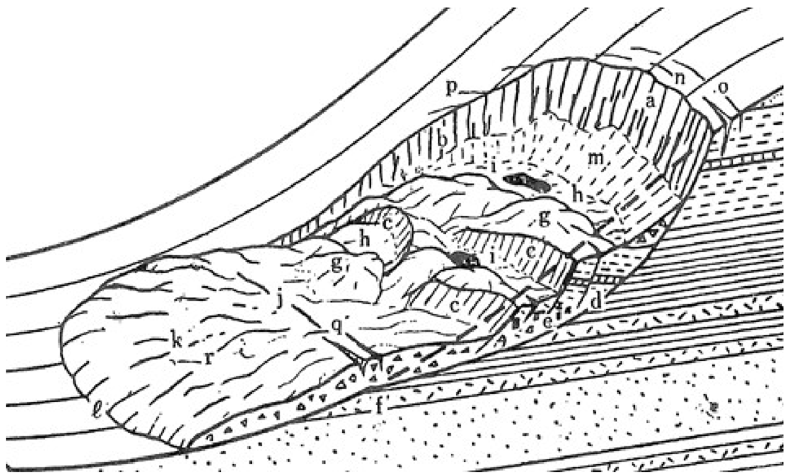


Fig. 6.11 Pattern diagram of landslide topography (Eisaku H. and Toyohiko M.i, 2012)

a. Main scarp, b. Lateral scarp, c. Secondary scarp, d. Main slide surface, e.Secondary slide surface, f.Toe part, g.Small prominence, h.Depression, pond (bog), j.Uplifted area, k. tongue, l.Tongue line, m.Talus, n.Crown, o.Crown fissures, p.Lateral (echelon) fissures, q.Fissures on uplifted area, r.Tongue fissures (collectively, g - l are called the landslide bank)- (Eisaku HAMASAKI1 and Toyohiko MIYAGI)

6.3.1.2 Regional Monitoring System

Causative factors that contribute to landsliding should divided into four categories: geological causes, morphological causes, physical causes and human causes. While there may be multiple causes for a landslide, there can be only one trigger (Varnes, 1978). (Wieczorek, G.F., 1996) stated that a trigger is "an external stimulus that causes a near-immediate response in the form of a landslide by rapidly increasing the stress or reducing the strength of slope material". For study area, trigger factor is high pore water pressor, which is result from high precipitation and directly relating to slope displacement. A full landslide monitoring system could measure many moving sensitive factors of landslide on site as full and muntil drection displacement of the vulnerable slope, moving directional displacement, slip displacement, precipitation, pored water pressor... Depending on propose of monitoring, sensitive factors selected are difference. Propose of regional monitoring system is predicted the relation ship between maximum precipitation of rain with displacement of landslides in target region.

Principle for regional monitoring system is "the conditions have led to past and present landslides can be used to identify cases likely landslides occur in the future." Actual landslide is full scale landslide experiment for monitoring. As dissucusing above, landslide-initiation mechanism is the effect of pore-pressure rising, that cause directly by rain. The precipitation of rain is absolutelymeasured and forecasted. The displacement signal of a slope was presented by pattern diagram of landslide topography, especially the landslide scarps (vertical displacement) and opening cracks (horizontal displacement). Both landslide displacement and rainfall parameters can be identifiable by measurement.

For a given region, from investigation and mapping, high risk occurred landslides and high susceptible locations will be marked as typical control points. The regional monitoring system should be set up for those in this region. The real signals of slope displacement and precipitation after rain could be recorded then the possibility of slope movement will be predicted from precipitation forecast. However, because of many number of control points it must be simple use and suitable for economic condition of mountainous region. For this reason, the real time or full monitoring system for landslide warning is not discussed in this guideline. There are two common monitoring equipments for precipitation and displacement of surface of slope is mentioned.

6.3.1.3 Rain Gauge - Rainfall Monitoring

Fig. 6.12-a shows a picture of a rain gauge, wich is often used to measure the amount of precipitation. The rain gauge consists of a funnel that collects and channels the precipitation into a small container.

Fig. 6.12-a Rain gauge Fig. 6.12-b Extensometer

After a pre-set amount of precipitation falls, the lever tips, dumping the collected water and sending an electrical signal. A rain gauge can be used for measurement of precipitation of a region.

6.3.1.4 Extensometers – Displacement Monitoring

Extensometers are devices used to measure the changing distance between two points. They are commonly used in the monitoring of landslides. Fig.6.12-b presented an arrangement of an extensometer for slope movement measurement in HaiVan landslide. Measurement points may be located on the surface of a landslide to measure ground movements, for example, spanning a tension crack to monitor its rate of opening, or in a borehole to measure differential displacements at depth for instance to identify active landslide shear surfaces. However, it will not feasible to set up extensometer for every landslide. So the simple way for record displacement is multi observation and manual measurement of signal of displacement such as width of crack, then opening of the crack, scarps opening scarps of landslide or the signal of rapid landslide movement, especially after rain.

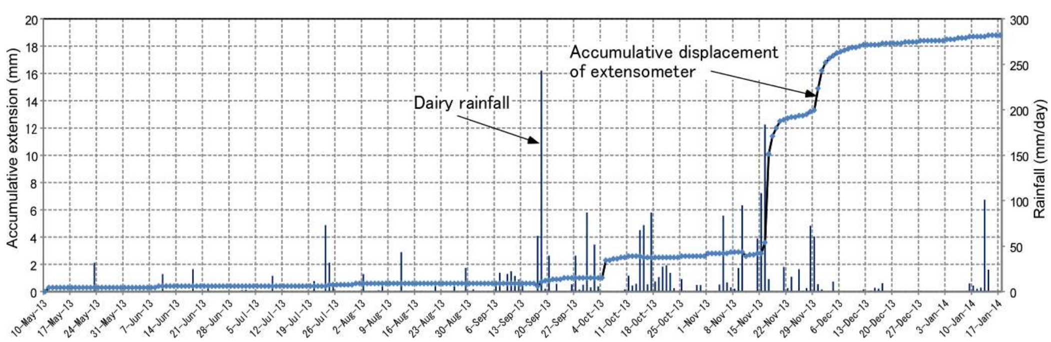


Fig. 6.13 The results of monitoring relationship between precipitation and displacement at Hai Van landslide – Vietnam

The result of relationship between precipitation of rain and displacement signal for should be done for creation the response plan to landslide.The results of monitoring relationship between precipitation (by Rain gauge) and displacement (by mono extensometer) at Haivan landslide – Vietnam in scope of 'Development of landslide risk assessment technology along transport arteries in Vietnam'' is presented in Fig 6.13 for reference.

6.3.2 Integrated Maps for Landslide Hazard Vulnerability Mitigation

6.3.2.1 Landslde Inventory Map

For development of the landslide hazard or risk assessment, the collection of information is considered as first step. This is the goal of landslide collection of information is creation of landslide inventory map. It records many information as the location, where known, the date of occurrence and types of landslides that have left discernible traces in an area (Hansen, A., 1984). A detail landslide inventory map could shows landslide boundary, shape, combine parts, topographical micro-features, direction of moving...Beside this landslide inventory map usually presented on the base of topography map which supplied for user surrounding information regarding geomorphology such as landform, stream network (gully/rill), convex breakline , concave.

Inventory maps can be prepared by different techniques, depending on their scope, the extent of the study area, the scales of base maps and aerial photographs, and the resources available to carry out the work. In this area, inventory maps was prepared by Air Photo scale 1: 33000 (one phase) and topo-map, which was extracted form DEM scale 1: 25000.

As they are prepared by interpreting one or more sets of aerial photographs and correcting the results by field investigation, landslide inventory maps tend to be subjective. Reliability, completeness and resolution are issues to be considered when preparing and using an inventory map. An incomplete or unreliable inventory may result in erroneous hazard or risk assessments. Many factors affect the reliability, completeness and resolution of an inventory map. Beside factors regarding to availability of input data such as landslide freshness and age, the quality and scale of aerial photographs and base maps, factors concerning to natural condition of area as the morphological and geological complexity of the study area, land use types and alterations, the human factor like degree of experience of the geomorphologist, who completes the inventory take a very important role. Good quality event inventories should be reasonably complete, at least in the areas for which aerial photographs were available and where it was possible to perform field work.

As a drawback, inventorymap often covers only a part of the total geographic area associated with a landslide triggering event. For the rest sensitive area, we have no information. In other hand, historical inventory landslide is never complete. Evidence for the existence of landslides is rapidly removed by erosion,growth of vegetation and human activity. And with time landslide boundaries become fuzzy, making it difficult to map the landslide precisely. However, because the synthesis and sufficiency regarding landslide information, landslide inventory Map is used for many propose of regional management.

6.3.2.2 Landslide Risk Assessment Map

Landslide risk evaluation aims to determine the "expected degree of loss due to a landslide (specific risk) and the expected number of live lost, people injured, damage to property and disruption of economic activity (total risk)" (Vaners, 1984).There are two possible approaches as quantitative (probabilistic) and qualitative approaches. Quantitative risk assessment aims to establish the probability of occurrence of a catastrophic event. However, the method requires a catalogue of landslides and their consequences. Because lack of the data of lost by landslide this evaluation is not discussed in this study.

A qualitative approach can be pursued in such a way as to establish qualitative levels of landslide risk. The landslide risk assessment map in this study was established based on interpretation of geomorphology-topography-airphoto. The landslide risk assessment map was developed from inventory map. In the process of air-photo interpretation, causative factors concerning to geological features, land used was considered together with characters of landslide topography micro features. An analytical hierarchical process (AHP) was used for evaluation the sensitiveness of reactive landslide by weight. As the results, a landslide risk assessment map is created, in which each landslide is coded. The risk level of each landslide is classified and divided in grades as low, middle, high and very high depending the sensitiveness evaluation to movement of each landslide.

Landslide risk assessment map is useful for ceration the landslide priority courtemeasures plan as well as other applications for management of region.

6.3.2.3 Landslide Susceptibility Map

Landslide susceptibility maps describe the relative likelihood of future landsliding based solely on the intrinsic properties of a locale or site. Some organizations use the term "landslide potential map" for maps of this kind.

There are various possible causes for land sliding with complex interrelationships. However, in practice a detailed assessment to find the main causes of each landslide is not feasible in most cases. The selection of causative factor for landslide susceptibility map is usually based on experts subjective experience. In this study, to analyse landslide manifestation, causative factors are derived of slope anger, type of rock, fault density, distance to the road, land used and precipitation. The maps for causative factors were created, in which each one was divided in to classes. From occured landslide distribution on the space from classes of causative factors map, the relation rule is concluded for future landslide prediction.

The sensitiveness to landslide of each classes zone of causative factor maps is calculated and then evaluated thought the value of number occurred landslide (NOL) and density of occurred landslide (DOL). These values were the result of comparison of landslide distribution map and each causative factor maps using GIS application. An analytical hierarchical process is used for evaluation. The combination these causative maps with difference evaluation weigh is carried out for landslide susceptibility mapping. As the result, a landslide susceptibility zonation map with for landslide susceptibility classes, i.e low, moderate, high and very high susceptibility for land sliding, is derived.

Landslide susceptibility maps are useful for disaster respond and mitigation plan, creation development master plan regading with plan for land use, construction of infracstructure.

6.3.2.4 Landslide Hazard Maps

Landslide hazard maps indicate the possibility of landslides occurring throughout a given area. An ideal landslide hazard map shows not only the chances that a landslide may form at a particular place, but also the chance that it may travel downslope a given distance. Landslide hazard maps is developed base on landslide information of inventory map, risk evaluation map and landslide susceptibility map. To a concrete landslide or high susceptibility slope, the tests for material for causative factors which triggered landslide will be done. A model experiment may invest for predict influence boundary of landslide when it would able to happen.

However, because it concerns to establish landslide hazard zone so concept of acceptable risk zone was discussed and not yet get the same point of view for every field. So landslide hazard maps is usuaslly developed and applied for concrete sensitiveness landslides or region depending on the purpose of regional manager.

6.3.3 Planning for Landslide Prevention and Mitigation

To landslide prevention and mitigation, depending strategies as prevention, response and mitigation, the following plans/program should be carry out.

6.3.3.1 Landslide Prevention Strategies

Landslide prevention concerning to understanding of landslide and potential of sliding. To prevent landslide hazard, a long-term strategies must be build as following advocacy, training and knowledge of landslide disaster prevention for the community. Main contents of Landslide prevention strategies includes (1) Building up landslide data base and (2) creation and application of inter-grade landslide hazard maps.

- Building up a landslide basic data , which was discussed above (refer to iterm 6.3.1 for details) for landslide management.
- Creation inter-grade landslide hazard maps as Landslide inventory map, landslide risk assessment map, landslide hazard map and landslide susceptibility map. The concept of them have been discussed above section. (refer to Item 6.3.2 and Table 6.3 landslide integrated guideline list for details). Using inter-grade landslide hazard maps for planning new residential development areas, land use and infrastructure development. For landslide prevention, the high susceptibility zone from landslide susceptibility map and high risk landslide from landslide risk assessment map should be avoided. Middle susceptibility zone or middle risk assessment should be considered for use. In case of inevitability, the strategies for landslide mitigation must be given out. To the new development area, which be located nearby easy landslide hazard vulnerability zone should be targeted for landslide predict calculation of stable factor and landslide hazard map for safety boundary.

6.3.2.5 Landslide Respone Strategies

- Establishing a public-domain information systems regarding landslide disaster to forecast and warning to community effectively. Information about the weather forcast regarding landslide such as locations, respone solutions, evacuation locations, waning sign, grade of risk assessement shoud be share to each family in sensitive area. Trial evacuation is necessary for action of community.

- Establishing regional monitoring system. There are many sensitive factor should be the target of monitoring. Depending on condition of each region, necessary factors is chosen. However, for the each region, 2 parameters including landslide displacement and precipitation of rain must be monitored for multi sensitive locations in the region (Regional monitoring system is discussed in 6.3.1.2). Please refer Table 6.3 for landslide integrated guideline list for details of other real time monitoring parameters.
- Creating respone solutions and evacuation plans base on integrated landslide maps and analyze results of sensitive factors from regional monitoring system. For example, from distribution of displacement of typical occurred landslides on precipitation chart, the reliability grade will be selected and evacuation plan is created. The safety area for evacuation will be selected based on inter- grade landslide maps on the low risk assessment and susceptibility zone.
- Establish the search and rescue force, which is ready for landslide occurring in order to rescue and mitigate the damage of phenomenon when disaster occures.
- Setting up the early warning system. In case of target such as local residents still stays on high potential of landslide moving area, a monitoring and early warning system should be set up. The training to people to understand and recognized emergency situation from the system is necessary. Please refer Table 6.3 for landslide integrated guideline list for details of landslide warning system.

6.3.2.6 Typical Mitigation Strategies

There are two basic strategies to mitigate for a particular landslide, that are (1) stabilization and protection countermeasures, which seeks to counter one or more key failure mechanisms and improve stability of the slope and (2) Maintenance and monitoring, which is applied when landslide countermeasures are ineffective. In this section, we do not discuss deeply for each countermeasures but guide for application scope.

- **Stabilization and Protection Countermeasures**

Depending on type of material as well as type of movement, landslide stabilization and protection countermeasures is divided into three categories as countermeasures for earth slope, rock slope and debris-flow. Table 6.2 presents the matrix of typical landslide countermeasures for mitigation strategies.

- **Countermeasures for Earth Slope Stabilization**

Excavation is common and quite low investment countermeasure for earth slope stabilization. Depend situation of landslide, following solutions will be applied as removal of soil from the head of a slide, reducing the height of the slope, backfilling with lightweight material, benches, reducing slope angle, or other slope modification. Before and during process of excavation, landslide movement stage must be considered carefully for safety.

Strengthening slopes is countermeasure that increasing the bearing capacity of the slope to unstable stage. The solutions include plastic mesh reinforcement, rockfill buttresses, stream channel linings or check dams to prevent check dam failure. Local available material should be used for those solutions.

As discussed above, water takes a very important role to stable stage of a slope by changing pore water pressure. Discharge water from landslide potential slope or landslide body is a very effective solution to stable stage. The drainage techniques includes site leveling, ditches and drains, drain pipes, straw wattles and straw bales, retaining walls, timber crib, steel bin wall, reinforced earth wall, gabion walls, piles. It could be combined with other solutions in order to get the targets of prevent water erosion and infiltration connecting with reduction of ground water.

For longterm and enviromental family countermeasure, slope stabilization using vegetation such as types of seeds, mulching or biotechnical slope protection solutions should be advised.

- **Countermeasures for Rock Slope Stabilization**

To rock slope, typical landslide that usually meet, especially on the cliff face or cutting taluy along the road is rockfall. For that kind of phenomenon, safe catching techniques countermeasure used will be simplest and the most effective. The catch ditches; cable, mesh, fencing, and rock curtains are solutions usually applied for rock fall or rock rolling.The retaining walls rock, sheds/shelters or rock ledge reinforcement are solutions that are built over the road or railway to prevent rock rolling or avalanches. They are usually relate to strong and heavy structure and take a large money for investment.

Excavation of rock countermeasure includes benches; scaling and trimming solutions. Benches solution is applied on rock cliff with high potential of translational slide. It also reduce tensional force in the surface and reduce surface erosion rates. In cases of rock cliff face with loose, unstable or overhanging blocks, scaling and trimming solution is advised as an initiative one. Beside mentioned countermeasure, rock cliff could be reinforced in place by application of shotcrete and gunite; anchor, bolt, and dowel solution.

- **Countermeasures for Debris-Flow**

As discussed in last part, the initial manifestation of the phenomenon of a debris-flow is erosion and erosional gully on the easy vulnerability slope by weathering, rain and other physical abrasion. Strengthening slopes for erosion/debris flows countermeasure could be used for strengthening as soil to resist erosion; proper planting of vegetation on slopes; keeping slopes free from fuel for wildfires solutions are considered as good one to prevent the possibility to make soil slope more prone to debris flow.

Structures for mitigating debris flows such as debris-flow basins, check dams, debris-flow retaining walls are solutions that can reduce the power of debris-flow by device it in to many portions and reducing its velocity. They could be built to stop or diverting it around a vulnerable area. In case debris flows make landslide dam, the following measure can be implemented as diversion of inflow water before it reaches the lake formed by landslide dam; temporary drainage from the impoundment by pumps and siphons; construction of an erosion-resistant spillway or drainage tunnel through an abutment.

- **Maintenance and Monitoring**

To the slope that has very large scale and high risk landslides,to which the using landslide countermeasures are ineffective, there are two solutions that are usually applied. They are (1) keep away from landslide and (2) Maintenance and monitoring.

Keep away from landslide solution often applies to large and very dangerous landslide. That is isolated landslide potential hazard area. Resident is not access or limited access to the landslide area for living. Landslide fences should be set up around the boundary. The boundary of limited assessment is divided depend the reliability of landslide hazard map.

Table. 6.2 Matric of typical landslide countermeasures for mitigation strategies

Countermeasures	Technique	Measures
Countermeasures for Earth Slope Stabilization	Excavation	-Removal of soil from the head of a slide, -Reducing the height of the slope, -Backfilling with lightweight material, -Benches, -Reducing slope angle, -Other slope modification.
	Strengthening slopes	-Lastic mesh reinforcement, -Rock-fill buttresses, - Stream channel linings -Check dams to prevent check dam failure.
	Drainage techniques	-Site leveling, -Ditches and drains, -Drainpipes, -Straw wattles and straw bales, -Retaining walls, -Timber crib, -Steel bin , reinforced earth , gabion walls, -Piles.
	Green	-Types of seeds, -Mulching -Biotechnical Slope Protection
Countermeasures for Rock Slope Stabilization	Safe Catching Techniques	-Catch Ditches Cable, Mesh, -Fencing, and Rock Curtains -Retaining Walls, Rock Sheds/Shelters -Rock Ledge Reinforcement
	Excavation of Rock	-Benches -Scaling and Trimming
	Reinforcing Potential Rock fall Areas	-Shotcrete and Gunite -Anchors, Bolts, and Dowels
Countermeasures for Debris-Flow	Strengthening Slopes for Erosion/Debris Flows	-strengthening the soil to resist erosion -Proper planting of vegetation on slopes can prevent erosion -Keeping slopes free from fuel for wildfires
	Structures for Mitigating Debris Flows	.-Debris-flow basins -Check dams -Debris-flow retaining walls
	Landslide Dam Mitigation	.-Diversion of inflow water before it reaches the lake formed by landslide dam -Temporary drainage from the impoundment by pumps or siphons -Construction of an erosion-resistant spillway -Drainage tunnel through an abutment

In case of keep away from landslide solution becomes infeasibility, maintenance and monitoring should be applied combining with early warning system. (refer guide line list for Early warning system). Generally, these measures are relatively low cost and can be highly effective in reducing public exposure to slide risk. Resident who live inside sensitive of landslide hazard map should be well trained for response evacuation when waning signal works.

Table. 6.3 Landslide intergraded guideline list

Code	No.	Name of guideline
Part	I	Mapping and Site Prediction
GL1	1.1	Landslide topography mapping through aerial photo interpretation
GL2	1.2	Field Work for Landslide Engineers
GL3	1.3	SFM base DSM establishing
GL4	1.4	Risk Evaluation of occurred landslide using the Analytic Hierarchy Process (AHP)
GL5	1.5	Landslide susceptibility mapping along the HCMR in the Central of Vietnam
GL6	1.6	Hazard zonation for Landslide Risk Reduction
GL7	1.7	Geological survey for landslide
GL8	1.8	Vulnerability of landslide hazard mitigation for humid tropical region
Part	II	Material Tests
GL9	2.1	High Stress Un-drained Ring Shear Apparatus (RSA) Introduction
GL10	2.2	Drained shear speed control test using RSA
GL11	2.3	Un-drained shear stress control test using RSA
GL12	2.4	Pore water pressure control test using RSA
GL13	2.5	Cyclic stress control test using RSA
GL14	2.6	Un-drained pore water pressure and seismic loading test using RSA
GL15	2.7	Soil shearing test in lab – Direct shear test
GL16	2.8	Portable Direct shear apparatus and testing
Part	III	Monitoring
GL17	3.1	Landslide Monitoring Systems
GL18	3.2	Measurement of slope surface displacement using Robotic total station
GL19	3.3	Measurement of slope surface displacement using Global Navigation Satellite System (GNSS)
GL20	3.4	Measurement of slope surface displacement using Extensometer

Code	No.	Name of guideline
GL21	3.5	Measurement of slip surface displacement in borehole using Inclinometer
GL22	3.6	Measurement of slip surface displacement in borehole using Vertical extensometer
GL23	3.7	Rainfall gauge and others Meteorological equipment
GL24	3.8	Groundwater observation using water pressure gauge
GL25	3.9	Early warning system
Part	IV	Landslide experiment
GL26	4.1	Outline of landslide experiment
GL27	4.2	Infiltration properties of testing material – for permeameter
GL28	4.3	Testing method (displacement measurement, pore pressure measurement)
GL29	4.4	Analysis of measured data (Landslide motion and pore water pressure)
GL30	4.5	Mechanism of landslide initiation
Part	V	Software and Simulations
GL31	5.1	Alcalc 3D Software
GL32	5.2	3D Analysis
GL33	5.3	Arc View Software - Arc GIS10.1/ Spatial Analysis Software
GL34	5.4	LS rapid

CHAPTER 7 – CONCLUSIONS AND RECOMMENDATIONS

In this chapter a brief discussion on the research of general landslide situation in Vietnam and the necessity of research on vulnerability of landslide hazard assessment will be presented. The conclusions will be drawn and general recommendations will be proposed from the data collection and the analysis of occurred landslide along the corridors of approximately 300 km of HCMR, which located in center zone of Vietnam - a typical tropical region. The conclusions will be drawn on what presented and discussed in previous chapters and the recommendation will be based on the experience gained in landslide studies during this research and other works carried out in Vietnam. Finally, topics for future work in continuation of this research will be presented.

7.1 General Landslide Situation in Vietnam

Landslides are viewed as a persistent problem in mountainous regions, especially distribute along transportation corridors. Landslides not only cause damage to properties (houses, buildings, vehicles, etc.) and life, but also affect the society by disrupting the utility services and economic activities. In order to reduce the impact of landslide on society it is necessary to understand then risk assessment for potential landslides for prevention and mitigation.

Located on the eastern Indochina Peninsula, Vietnam has a rate of mountainous terrain up to 3/4 area of its territory with a dangerous cleavage terrain due to earth's crust powerful tectonics. Moreover, it has complex geological structures and the monsoon climate with the average annual rainfall from as much as 3,000-4,500mm/year in some regions so Vietnam becomes area with the most serious landslide disaster in Southeast Asia and the Mekong subregion.

According to statistics of the Central Steering Committee for Flood, from 2000 to 2014, it was occurred 250 debris flows and landslides affect residential areas. This landslides caused 646 people dead and missing, nearly 351 people were injured; more than 9,700 homes were poured away; more than 100,000 homes were flooded and damaged; more than 75,000 hectares of rice and vegetables flooded ... total damage estimated at over 3,300 billions Vietnamese Dong, equivalent 150 millions USD . Thus, we can say landslides phenomenon is one of the serious natural disasters in Vietnam, and is a topical issue hot for Vietnamese government in general and MOT in particular. Strategy for natural landslide disaster prevention, response and mitigation of Vietnamese government has approved since 2007, in which vulnerability of landslide hazard assessment was one very important issue in this "proactively prevent natural disasters" strategy.

7.2 Research Targets and Contents

Vulnerability of landslide hazard is portability of slopes by landslides. Slope portability includes the sliding of original slope (the slope that in its history creation process got erosion only) and the slope has occurred landslide in the past. To occurred landslide slope, this moving is considering as re-active landslide. Vulnerability of landslide Hazard assessment is large concept concerning to landslide risk assessment to re-active landslides and the landslide susceptibility to slope finally.

Purpose of study are development comprehensive method for assessment vulnerability of landslide hazard of slope for tropical region through collection of occurred landslides on study area since 2006 to 2014; creation landslide distribution map; studying significant methods for landslide classification; analyzing relationship of landslide phenomena with causative factors and creating landslide risk assessment map and Landslide susceptibility map for Vulnerability of Landslide Hazard assessment. However, huge quantity of the study, Landslide risk assessment map for to re-active landslides is not in scope of the dissection.

The target of the study area is a corridors of approximately 300 km of HCMR, which located in center zone of Vietnam - a typical tropical region.

The contends of research include The general method for Landslide prevention and mitigation for road in humid tropical region; Geological mechanisms of landslide generation along HCMR in the Central of Vietnam; A prediction of Landslide Classification by pattern recognition of fuzzy inference method along the HCMR in central zone of Vietnam; Landslide susceptibility mapping along the HCMR in the Central of Vietnam - AHP approach applied to a humid tropical area and Guideline for vulnerability of landslide hazard mitigation in tropical region.

7.3 The General Method for Landslide Prevention and Mitigation for Roads in Humid Tropical Regions

The landslide phenomenon is considered as a natural disaster directly affected the development of mountainous areas in general to the traffic and transportation sector particularly. From the damages of typical landslides in Vietnam such as on Highway No. 37 (at Chen Pass), Son La Province, The Nam Non Bridge on the Western Route, Nghe An Province, at Hai Van Pass Station, on Highway No. 6 and along the HCMR in the Central, it is able to be recognized that the responding in face to this dangerous phenomenon seems to be quite passive.

This research proposed a new strategy proactively to prevent and mitigate the occurrence of this natural disaster for the new design and management of roads through mountainous terrain areas. The core of the new strategy is to build up a Vulnerability of Landslide Hazard map by the combination of the Landslide risk assessment map (LRAM) which based on methods of collect historical data, field surveys and interpretation of aerial photos and the Landslide susceptibility map (LSM) which is analysed from landslide manifestation in study area and landslide causative factors such as topography, geomorphology, geology, climate and human impact as a basis for predicting the future.

Landslide risk assessment is the comparison of the sensitiveness to activate slide among investigated landslides. The landslide information form basic data concerning to position, micro features and causative factors is very important for the assessment. The topography features of occurred landslides will be target for study relating to relative causative factors such as geology, morphology, climate... For comparison and assessment, methods of analytical hierarchical process approach or fuzzy relation could be applied. Depend on weigh value of the assessment, the sensitiveness to re-active sliding will be divided in classes of sensitive groups as low, moderate or high.

To assess landslide susceptibility, the identification of causative factors, which are classifiable 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) usually targets of the study. Actually, the landslide process depends on many causative factors such as topography and geomorphology, geology, climate, and human impact. However, depending on concrete study zone, the relevance, availability and scale of map (Slide and Ochiai 2006), necessary factors should be used. Therefore, I recommend as objects of analysis for this study, minor and indirect factors were ignored in favor of factors 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 map, in which each factor map of the study area was classified into many different classes groups. The weight of each factor will be considered base on results of analysis relation between occurred Landslide with each classes factor map using GIS. Methods of analytical hierarchical process approach or fuzzy relation are applied for evaluation the weight contribution of each factor then overlay causative maps with calculation weighs are carried out. As the results, 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 effective for Vulnerability of landslide hazard assessement.

To assess vulnerability of landslide hazard, I recommend that the landslide risk assessment map (LRAM) and landslide susceptibility map (LSM) and their combination will be effective tools for forecast, prevent and mitigate the negative impact of the landslide phenomenon for planning, land use, especially to reducing the damage of landslide phenomena arising due to climate change to traffic systems particularly and the development of infrastructure in general. This, which bases on those kind of maps will be a newapproach for the "proactively prevent natural disasters" strategy.

7.4 A Prediction of Landslide Classification by Pattern Recognition of Fuzzy Inference Method along the HCMR in the Central of Vietnam

From 2012 to 2014, multi Landslide investigation have been taken a long HCMR in order to collect as many as occurred landslides for landslide risk assessment and landslide susceptibility mapping. According to Varnes classification, the occurred landslides were classified. However because of complicated phenomena and depending on point of observations, there were some landslide cases which had a non-consensus for classification.

Therefore, a study of Landslide Classification by pattern recognition of fuzzy inference method along the HCMR is proposed for study. For landslide mitigation, a degree of risk valuation and the construction of prevention measures are necessary to prevent these landslide disaster. So it is necessary to execute a pattern recognition of different type classification. Cause of landslide having a various moving style, but the analysis of this type classification is affected by the various factors therefore we examine this analysis method of Landslide Classification in consideration of fuzzy nature. From the results of research,the following conclusions were obtained.

Few studies of Landslide Classification have been conducted to date. No elaborate or economic survey has been conducted to formulate or assess preventive measures. Accordingly, a Landslide Classification procedure using fuzzy theory considering ambiguity was examined for implementing high-precision, economical, on-site inspection. We have demonstrated that the type classification procedure based on fuzzy if-then rules is beneficial through comparison with the multi-group linear discriminant method.

Because the classification procedure by fuzzy if-then rules differentiates confidence values in Landslide Classification, the importance of the combination of attribute factors can be estimated. We have shown that the linguistic expression of if-then rules on the combination of these attribute factors is easy to understand for general engineers because it resembles human reasoning processes.

Weathering, Geology, and Scale are important attribute factors in Landslide Classification at roadside slopes of the Ho Chi Minh road; the landslide types can be ascertained. Future tasks include accumulation of many more data for training for additional precision improvement in Landslide Classification, was well as additional examination of attribute factors effective in classification.

I recommend that the propose method is high technique analysis precision and could be applicated for similar assessment application.

7.5 Geological Mechanisms of Landslide Generation along HCMR in the Central of Vietnam

In the Central of Vietnam, HCMR (HCMR) runs from south to north along the border with Laos. In this area, HCMR is often closed due to numerous landslides during the rainy season. Thus, there is an urgent need to determine the generation mechanism of landslides and to conduct risk assessment.

For this purpose, the area was chosen as one of the study areas for this project. This study focuses on landslides occurring at approximately 180 locations along the 150 km distance (linear distance) from Thanh My (west of Da Nang City) and the intersection with National Route 9 (west of Quang tri). The landslides are classified based on the type of movement in order to determine the triggering mechanism. The survey was conducted from 2012 to 2014. The results are described below.

In this study area, many landslides occur as a road hazard. These landslides have a movement type characteristic of the geology and weathering of the area. Therefore, landslides in this study area were classified into translational rock slides, translational shallow debris slides, translational wedge type slides, rotational slides, gully type slides and flows, and rock falls.

The occurrence of these landslides is related closely to the geology of the area and weathering. In other words, in Paleozoic sedimentary rocks in the northern part of the study area, rotational slidesare common in the weathered area.Translational shallow debris slides are common in the weakly weathered area. Gully style slides and flows are most common in metamorphic rocks in the central part of the study area, concentrated in the strongly weathered areas. In areas with weak weathering, translational shallow debris slide is more common. Most landslides in Mesozoic sedimentary rocks in the south are translational rock slides using coal seams as the sliding surface.

Weathering of Metamorphic rocks in the central area is advanced deeper because of penetration of rainwater through weak surfaces such as schistosity and joints, and also because of the development of faults. In the study area, translational wedge type slides develop using the intersection of these weak surfaces as the sliding surface. With increased weathering, this develops to gully type slides and flows. Landslides in sedimentary rocks of the southern part of the study area are controlled by cracks in the bedrock. Coal seams in sandstone and conglomerate acting as the sliding surface are fractured. They have many small faults. These small faults in the coal seams have different orientations from the fault direction and the dip of the whole study area. Therefore, it is regarded as deformation structures in sandstone and conglomerate as a brittle competent layer and muddy coal seams as a ductile incompetent layer associated with folding structures.

Mesozoic mud stone, sandstone, and conglomerate (excluding coal seams), and Paleozoic schist and gneiss/granite are truncated by faults with the strike of N–S to NW–SE and a high-angle dip of 70–90°. Consequently, faults likely occurred post-Mesozoic because of uplifting of granite.Moreover, the scrape directions for several fault surfaces show low angle bedrock displacement in the range of 30°–50°.

The results presented above showed that landslides in the study area have various movement types. Widely various geology and geological structures lead to these various movement types, such as cracks forming in association with post-Mesozoic folds and faults, fracturing of coal seams associated with fold structures, weathering of bedrock caused by percolation of rainwater along cracks, and development of cuesta landforms

I recommend that these landslides are not simply caused by heavy rain and weathering typical of the tropics, but are closely associated with geology, geological structure, development of rivers, and cuesta topography. This result shall be an important indicator in future study of Vulnerability of Landslide Hazard.

7.6 Landslide Susceptibility Mapping along the HCMR in the Central of Vietnam - an Application of an AHP Approach to Humid Tropical Regions

Landslide is considered as one of the dangerous phenomenon that often occurs in the mountainous region of Vietnam and directly affects to the lives of the people in the region, destroys the traffic infrastructure the road system. This paper introduces an overview of the natural conditions of the study area which locates along the corridor of the HCMR, in the provinces of Quang Tri and Thua Thien-Hue, Quang Nam in order to focus on the spatial analysis of landslide susceptibility in this area.

There are various possible causes for land sliding with complex inter–relationships. However, in practice a detailed assessment to find the main causes of each landslide is not feasible in most cases. The selection of causative factor for landslide susceptibility map is usually base on expert's subjective experience. In this study, To analyse landslide manifestation, causative factors are derived of slope anger, type of rock, fault density, distance to the road, land used and precipitation. Maps for causative factors were created, in which each one was divided in to classes.

From position of 604 slope failures appeared along the HCMR a landslide distribution was build up. The sensitiveness to landslide of each classis zone of causative factor maps is calculated and then evaluated thought the value of number occurred landslide -NOL and density of occurred landslide DOL. These values were the result of comparison of landslide distribution map and each causative factor maps using GIS application. An analytical hierarchical process is used to combine these maps for landslide susceptibility mapping.

As the result, a landslide susceptibility zonation map with 4 landslide susceptibility classes, i.e low, moderate, high and very high susceptibility for land sliding, is derived based on the inventory map of observed landslide from 2006-2009. Overlapping of the landslide distribution map and landslide susceptibility map showed that 26, 80, 255,and 244 landslides in all of 604 recorded landslides were respectively located in low, average, high, and very high susceptibility areas for landslides. Therefore, 40.40% of the landslides were in the very high susceptibility areas; 42.22% of the landslides occurred in high susceptibility areas; 13.25% of the landslides occurred in middle susceptibility areas; only 4.14% of landslides occurred in low susceptibility areas. Specifically regarding high and very high susceptibility areas, 82.66% all landslides occurred there.

I recommend that even there was limited matter concerning relevant, scale and available data, the landslide susceptibility map of this study for corridor along this road is credible for landslide mitigation.

7.7 Guidelines for Landslide Hazard Vulnerability in Humid Tropical Regions

This guideline for Landslide hazard vulnerability management for region is one of 34 integrated guidelines for landslide risk assessment , which was developed by the cooperation research project ‘’Development of landslide risk assessment technology along transport arteries in Vietnam’’. The integrated guideline Set includes 5 parts, covers on (1) Mapping and Site Prediction, (2) Material Tests, (3) Monitoring, (4) Landslide flume experiment, (5) Softwares and Simulations. The detail list of intergrated guideline list is presented in Table 6.2 for reference.

This guideline covers on characteristics of landslides in study area for classification, landslide moving mechanism, landslide dynamic factors and the relationship between dynamic factor and signal movement of landslide recognition. Beside this tools for landslide management for region such as basic data for landslide management (such as Landslide data base, Regional monitoring system) as well as concept of landslide integrated maps for landslide hazard vulnerability mitigation (such as landslide inventory map, landslide risk assessment map, landslide susceptibility map, landslide hazard map) are presented.

The following plans/programs established as guidelines include: prevention, response and mitigation. (i) Landslide prevention concerning to understanding of landslide and potential of sliding. To prevent landslide hazard, Long-term Strategies as advocacy, training the knowledge of landslide disaster prevention for the community; building up landslide data base; creation and application of inter-grade landslide hazard maps for regional management were advised. (ii) To landslide response strategies, the following works including establish information systems disaster warnings forecast landslide to effective community; maintain a public-domain information of inter-grade landslide hazard maps of landslides; establishing regional monitoring system; creating evacuation plant; establishing the search and rescue force; Building up Early warning system should be carried out depending concrete location of target region. (iii) There are three basic strategies to mitigate for a particular landslide as stabilization and protection; avoidance and maintenance - monitoring are presented.

7.8 Conclusions and Future Research

Vulnerability of Landslide Hazard assessment is one very important issue in the "proactively prevent natural disasters" strategy of Vietnamese government. Strategy of the research following the principle " for the landslides, the past and the present are the key to the future" (Vaners, 1984); (Carrara, et al., 1991).

Form landslides survey data in corridors of HCMR,Vietnam, the following matters including: the general method for landslide prevention and mitigation for road; the prediction of Landslide Classification by pattern recognition of fuzzy inference method; Geological mechanisms of landslide generation along HCMR and Landslide susceptibility mapping have been studied and giving out results. A Landslide hazard vulnerability guideline for tropical region was established. The research results, which were carried out in the Central of Vietnam - a typical tropical region can be applicated for other similar tropical one. Vulnerability of landslide hazard assessment is large matters. Beside of above studies, the air photo interpretation for creation of landslide inventory map, Landslide Risk Assessment to re-active landslides was not mentioned in this study. For future study, base on the outcome of this research and considerring the stage of development of landslide risk research, the following future work in continuation of this research is suggested as below:

- Creation of landslide topography, inventory map applying air photo-interpretation tecnology and developing the landslide detail inventory and classification map.

- The relationship between landslide micro features mechanisms with causative factors such as topography, geomorphology, geology, climate and human impact.

- Study on landslide landslide risk assessment to re-active landslides using fuzzy, AHP or combination of Fuzzy and AHP method.

- Study on landslide susceptibility using fuzzy method or combination of Fuzzy and AHP method.

References

Abe, S. . (2014). Topographic and geological factors of landslides along HCMR in central Vietnam. *SATREPS Worksho* (pp. 107-118). Hanoi: ITST.

Abe, S. (2013). Key points in field Work for Landslide Engineers. In ICL, *Landslide Teaching Tools* (pp. pp 89-115). Tokyo, Japan: ICL & UNESCO.

Abe, S. e. (2014). Topographic and geological factors of landslides along HCMR in central Vietnam. *SATREPS workshop on landslides in Vietnam* (pp. 1-12). Hanoi: ITST.

Aksoy, B. and Ercanoglu, M. (2012). Landslide identification and classification by object-based image analysis and fuzzy logic: An example from the Azdavay region (Kastamonu, Turkey). *Computer & Geosciences, Vol.38*, 87-98.

Aydin, A. (2004). Fuzzy set approach to classification of rock masses. *Engineering Geology, Vol.74*, 227-245.

Bui, D.T. et al. (2012a). Spatial prediction of landslide hazrds in Hoa Binh province (Vietnam): A comparative assessment of efficiency of evidential belief functions and fuzzy logic model. *Catena, Vol.96*, 28-40.

Bui, D.T. et al. (2012b). Landslide susceptibility mapping at Hoa Binh province (Vietnam) using an adaptive neuro-fuzzy system and GIS. *Computer Geosciences, Vol.45*, 199-211.

Cabalar, A.F. et al. . (2012). Some applications of adaptive neuro-fuzzy inference system (ANFIS) in geotechnical engineering. *Computers and Geotechnics, Vol.40*, 14-33.

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

Champatiray, P.K. et al. (2007). Fuzzy based for landslide hazard assessment in active seismic zone of Himalaya. *Landslides, Vol.4*, 101-111.

Demicco, R.V. and Klir,G.J. (2004). *Fuzzy logic in geology.* New York: Elsevier Academic Press.

Eisaku H. and Toyohiko M.i. (2012). TXT-tool 1.081-2.3 Abstracting unstable slopes (landslide topography) using aerial photos and topographic maps:Concept and frameworks. In ICL, *Landslide teaching tools* (pp. 22-35). Tokyo: ICL.

Eisaku HAMASAKI1 and Toyohiko MIYAGI. (n.d.). Risk Evaluation using the Analytic Hierarchy Process (AHP) – Introduction to the process concep. In ICL, *Landslide teaching tools* (pp. 36-49). Tokyo: ICL.

Ercanoglu, M. and Gokceoglu, C. (2004). Use fuzzy relation to produce landslide susceptibility of a landslide prone area (West Black Sea Region, of Yenice, Turkey). *Engineering Geology, Vol.75*, 229-250.

Ercanoglu,M. and Gokceoglu,C. (2002). Assessment of landslide susceptibility for a landslide-prone area (north of Yenice, NW Turkey) by fuzzy approach. *Environ. Geology, Vol.41*, 720-730.

Fell, R. et al. (2000). Keynote lecture- Geotechnical engineering of the stability of natural slopes, and cut and fills in soil. *GeoEng2000, Ann. Inter. Conf. Geotec. and Geol. Engin.*, 21-120.

Greenway, D. R. (1987). Vegetation and slope stability. In M. a. Anderson, *Slope stability, geotechnical engineering and geomorphology.* Chichester: Wiley.

Hai D. H and Ho Chat. (2002). *Prevention of damages on mountainous road foundations.* Hanoi: Transportation.

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

Ho Chat and Tam D. M. (1985). *Manual for Mitigation and Stabilization of Road Embankments.* Hanoi: Transportation.

Hunger, O. et al. (2014). The Varnes classification of landslide types, an update. *Landslides, Vol.11*, 167-194.

JOGMEG - Japan Oil, G. a. (2000). The Socialist Republic of Vietnam. *Environmental Research On Resources Development*, 52.

Kyoji, S. and Bin HE. (2012). TXT-tool 3.081 -1.1 Landslide Initiation Mechanism. In ICL, *Landslide teaching tools* (pp. 205-214). Tokyo: ICL.

Kumanan, S. et al. (2008). Application of multiple regression and adaptive neuro fuzzy inference system for the prediction of surface roughness. *Int. Jour. Adv. Manuf. Technol. Vol.35*, 778-788.

Lee, S. and Talib,J.A. (2005). Probabilistic landslide susceptibility and factor effect analysis. *Environmental Geology. Vol.47*, 982-990.

Long N. T. (2012). Application of an analytical hierarchical process approach for landslide susceptibility mapping in A Luoi district, Thua thien Hue province, Vietnam. *Environmental Earth Sciences, Volume 66, Issue 7*, 1739-1752.

Ngoc N. S. (2005). *Classification of slope movements.* Hanoi: Transportation.

Nozaki, K.et al. (1994). Knowledge Acquisition with Trainable Fuzzy Classification Systems. *Journal of Japan Industrial Management Association, Vol. 45, No. 5*, 430-441.

Oh,Hyun and Pradhan,B. (2011). Application of a neuro-fuzzy model to landslide-susceptibility mapping for shallow landslides in a tropical hilly area. *Computers & Geosciences, Vol.37*, 1264-1276.

Oldrich, H. (2014). The Varnes classification of Landslide type, an update. *Landslides*, 167-194.

Pourghasemi, H.R. et al. (2012). Application of fuzzy logic and analytical hierarchy process (AHP) to landslide susceptibility mapping at Haraz watershed. *Iran. Nat. Hazards Vol.63*, 965-996.

Pradhan, B. (2010). Application of an advanced fuzzy logic model for landslide susceptibility analysis. *Comput. Intell. Sys. Volume 13, No. 3*, 370-381.

Pradhan, B. (2013). A comparative study on the predictive ability of the decision tree, support vector machine and neuro –fuzzy models in landslide susceptibility mapping using GIS. *Computers &Geoscience, Vol.51*, 350-365.

Pradhan, et al. (2010). A GIS-based back-propagation neural network model and its cross-application and validation for landslide susceptibility analysis. *Comput. Environ. and Urban Sys., Volume 34*, 216-235.

Saaty, T. L. (1997). A scaling method for priorities in hierarchical structures. *J. Math. Psychol.Vol. 15*, 234–281.

Saaty, T. L. (2000). *The fundamentals of decision making and priority theory with the analytic process, Vol VI, 2nd edn. .* Pitsburg: RWS Publications.

Saboya, F. et al. (2006). , Alves,M.G. and Pinto,W.D.(2006): Assessment of failure susceptibility of soil slopes using fuzyy logic. *Engineering Geology, Vol.86*, 211-224.

Sarkar, S. et al. . (1995). Landslide Hazard Zoning: a case study in Garhwal Himalaya, India. *Mt. Res. Dev.Vol. 15, No. 4*, 301–309.

Slide, R. C. and Ochiai, H. (2006). *Landslides: processes, prediction, and land use (Water resources monograph).* Washington: Amer Geophysical Union.

So, C.L. (1971). Mass movements associated with the rainstorm of June 1966 in Hong Kong. *Inst Br Geogr*, 55-65.

Theresa, M.M.J. and Raj, V.J. . (2013). Fuzzy based genetic neural networks for the classification of murder cases using Trapezoidal and Lagrange Interpolation Membership Functions. *Applied Soft Computing, Vol.12*, 743-754.

Tien D. V. et al. (2014). Landslide prevention and mitigation for road in humid tropical region. *The 4th volume of World Landslide Forum 3 (WLF3)* (pp. 716-724). Beijing: ICL.

Tien, D. V. et al. (2015). Geological mechanisms of landslide generation along HCMR in central Vietnam. *Journal of Japan Landslide Society, Vo.l 52, No4 (226)* .

Tien, D. V. et al. (2016). A prediction of landslide type classification by pattern recognition of fuzzy inference method along the HCMR in central zone of Vietnam. *Geomorphology vol.37-1*.

Tien, D. V. et al. (2016). Landslide susceptibility mapping along the HCMR in central Vietnam - an application of an AHP approach to humid tropical area . *Geomorphology, Vol.37-1*.

Tien, D. V. et al. (2016). Outline, typology and the causes of Landslides in Vietnam. *Geomorphology Vol.37-1*.

Tien, D.V. (2010). *Application of analytical hierarchical process approach for landslide susceptibility mapping in zone which locates along Ho Chi Minh road from Nghe An Province to Kon Tum Province.* Hanoi: Ministry of Transport of Vietnam.

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

Toyohiko, M. (2004). *Landslide Risk Evaluation and Mapping – Manual of Landslide Topography and Risk Management.* The national Research Institute for earth Science and Disater Prevention.

Tran , T. V. and Tien, D. V. (2006). *Report the results of the project - Survey to assess the status, the risk of landslides some sections of the Ho Chi Minh Highway, National Highway 1A and caustic treatment measures ensure traffic safety, productio.* Hanoi: ITST.

Tran. (1995). *The geology of Vietnam, A brief summary and problems.* Shizuoka, Japan: Shizuoka University.

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

Varnes, D. J. (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.

Vhahidnia, M.H.et al. . (2010). A GIS-bases neuro-fuzzy procedure for integrated knowledge and data in landslide susceptibility mapping. *Computer & Geosciences, Vol.36*, 1101-1114.

Wang, W.D et al. (2002). Landslides susceptibility mapping in Guizhou province based on fuzzy theory. *Mining Sci. and Tech., Vol.19*, 399-404.

Wieczorek, G.F. (1996). *Landslide triggering mechanisms: Investigation and Mitigation.* Washington D.C.: Transportation Research Board.

Yalcin, A. (2008). GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey): Comparisons of results and confirmations. *ScienceDirect, Volume 72, Issue 1*, Pages 1–12.