Total Management of Landslide Disaster Risks along Main Roads in Tropical Mountain Ranges

Dissertation

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Preface

Vietnam is a country suffered by landslide disasters due to the tropical monsoon, strong cleavage of terrain, tropical weathering of rocks and rapid and extensive development of land in progress of economic growth. The landslide killed about 30 people each year, causing hundreds of millions of US dollars damage, made traffic congestion and anxiety for people, especially in and after the rainy season. The establishment of effective landslide risk assessment technology is very much needed for nationwide safer geoenvironment and securing transport arteries.

Japan has much suffered by landslides triggered by typhoons, strong/long rainfall, snow melting as well as earthquakes. The necessity to reduce landslide disasters has promoted landslide science and technology in Japan. Results are landslide risk assessment technology as well as the research and application of early warning systems for mitigation and prevention of landslides in Japan recently have made great advances.

A JICA-JST joint project contributing to the landslide risk reduction in Vietnam have been implemented in 5 years from 2011-2016. This is the SATREPS project titled "Development of landslide risk assessment technology along transport arteries in Vietnam". The greatest purpose of the project was to create human resources for the landslide risk reduction in Vietnam through education and technology transfer from Japan to Vietnam. Apparently, it is the most basic and important factor for sustainable development of landslide risk reduction in Vietnam.

For this purpose, 4 workgroups have been established and implemented a series of activities. (1) WG1 is a Joint Team of all groups, prepare the integrated guidelines for the application of developed landslide risk assessment technology and capacity development, (2) Task of WG2 is the Mapping Group prepare Wide-area landslide mapping and identification of landslide risk area, (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 the final output of my study under the supports of members of WG2. This study likes to propose a framework of total management for landslide disaster prevention, mitigation and the control suitable for Vietnam. It starts from the data collection, landslide topography mapping, field investigations, soil strength evaluation, susceptibility mapping and reactivation risk evaluation, risky site prediction, risk evaluation in the site, monitoring and countermeasure. A concept of countermeasures and monitoring will be integrated into one workflow, to indicate a procedure to be conducted in each phase. I hope, this total management system might be applied for Vietnam as well as to all of Southeast Asia as a humid tropical zone.

First of all, I pay my sincere gratitude to ITST leaders, Prof. Kyoji Sassa and the honorable every renowned Professor of different University in Japan, many officers and engineers from Government and private sectors, field officers and Japanese coordinators, who give us some chances to study in Japan, many research experiences.

I would especially like to thank Prof. Toyohiko Miyagi, Dr. Eisaku Hamasaki, Dr. Tatsuya Shibasaki, Dr. Shinro Abe, Dr. Daimaru, Dr. Hayashi, Prof. Noriyuki Chiba, Dr. Hiroyuki Yoshimatsu, Mr. Takesi Katoh and the other members of WG2 of Vietnam project, who have contributed their outstanding efforts through their presentations, lectures, site visits and laboratory testing for the support to complete my study.

Abstracts

Landslide in mountainous terrain is a natural degradation process and one of the most important landscape building factors. Most of the terrain in mountainous have been and trend generally subjected to slope failure under the influence of a variety of causal factors and triggered by issues such as geological shocks or rainfall or flood. The frequency and magnitude of slope failure can be increased due to human activities such as deforestation and urban expansion or build road, dam, and build hydropower reservoirs, etc. The event may disrupt the normal rule of human lives and if the higher the magnitude of event happens, community needs outside support to recover. Unfortunately, this phenomenon is common in Vietnam.

Three-quarters of Vietnam's territory is mountainous and the territory runs along the coastline of the South China Sea, so it is directly affected by humid tropical climate. Annually, Vietnam directly suffered from 5-7 tropical cyclones, heavy and persistent rainfall causes floods, flash floods, mudslides, and landslides. In addition, Vietnam has a complicated geological structure, high density of faults, accompanied by intense weathering of rock, and rapid construction speed in recent years have made landslide more frequency and serious. In particular, landslides occurred along the new and upgrade construction roads have caused unsafe and disruptions.

According to statistics, the landslide has average killed about 30 people, causing hundreds of millions of US dollars in damage each year. The Vietnamese government as well as the sectors of construction, transportation and irrigation have spent hundreds of millions of dollars in rehabilitation as well as research to reduce and prevent the landslide. However, the efficiency is not as satisfactory as expected. Meanwhile, due to the effects of climate change, natural hazard prediction studies, including the risk of landslides continue to increase both in terms of severity and frequency of occurrence. Therefore, the study of building an effective management model to mitigate landslide is still a very urgent practical requirement in Vietnam.

The recent studies have built a database of landslide distribution, landslide

susceptibility maps in some areas for the purpose warning to local residents. For example, landslides risk map in Vietnam by Institute of Science and Technology (2006); the landslide distribution map along HCMR from Nghe An to Kontum by ITST (2012); landslide distribution maps in 15 provinces in the Northern mountain by Institute of Geology, Mineral Vietnam (2013); Maps of landslide topographic area from Prao to Kham Duc along the HCMR by Le et al., (2016). A new strategy for landslide hazard vulnerability mitigation in the humid tropical region was proposed by Tien et al., (2014), which proposed the landslide classification by pattern recognition using fuzzy inference method, landslide susceptibility mapping by the AHP approach applied and mentioned to some guidelines for landslide hazard vulnerability mitigation in humid tropical. In addition, the method of landslide mapping of aerial photograph interpretation and risk evaluation and approach for a humid tropical region are also mentioned and built by Luong et al., (2015). This is the method considered supposed to be suitable for large-scale landslides (Luong et al., 2016), while aerial photo data and taking new aerial photographs in Vietnam was not necessarily easy (Dung et al., 2016). Newly taken aerial photographs require huge expenses that are expected to challenge any realistic research budget. In addition, aerial photographs of the mountain region taken in the past were on a scale of about 1:33,000, clarifying that they were unsuitable for the recognition of micro landforms from them (Dung et al., 2016).

Other studies have studied the cause and proposed landslide response solutions for a specific landslide or areas. It shows that there were causal factors and triggers factors (Tien et al., 2014), and seems to be a relationship between the potential of landslides and the characteristics of the humid tropical climate (Abe et al., 2014). However, there is not any complete research on the mechanism of the phenomenon, the impact of weathering of rocks in the humid tropical climates area to the risk of landslide. Special, the identification of reality slip surface is a very important factor for risk assessment and make a decision of monitoring or countermeasures. That has not been mentioned yet (Dung et al., 2016). As the statistics and a series of field investigations showed that mainly type of landslides along routes is the shallow landslide, with small to medium scale (Dung, 2016). Rarely landslide occurs in a deep slide type. It is meaning that landslides appeared in the area of the surface geological layers, which is directly affected by weathered. In addition, the result of field investigations showed that a thin layer of geology often appears, which is very weak of strength, heavily weathered, easily swollen and reduced the strength by saturated. This layer was sandwiched between the upper layers of weathered rocks and the underlying fresh rock layers. This is usually the position of the slip surface when sliding occurs.

This dissertation tries to clarify the relation of potential landslide risk with geological structure, level of weathering and strength of the rocks by establishing methods of field investigations, risk assessment and classification consistent with the characteristics of landslides in the humid tropical country like Vietnam. At the same time, developed the method of identifying real slip surface by field investigation techniques, and like to clarify the actual landslide and the slip surface mechanism. The next step for use the data collected so that simulate the real slip surface, assessing the safety factor in strong weathered and the saturated environment in the tropical country. Final, we suggest the research plans and the countermeasure against landslides disaster depending on our situation. For example, such approach could be possible.

The subjects and scopes of the study are landslides along transport arteries of Vietnam. Case studies are including a typical landslide on NH6 located at 95 km far from the starting point of NH6 at Hanoi, about 350km long along HCMR corridors in the Central, and about 70km long of NH7 in Nghe An province (section from Muong Xen to Son Ha).

For this study, we collected the history data on landslides occur in the past and by a series of field investigations. First, we collected the general data of climate condition, topography and geological in Vietnam. Because of the location of Vietnam in Southeast of Asia, Vietnam suffered and directly affected by monsoon climate. In the high terrain mountainous of Northern and Central have the complex geology and the concentration of highest precipitation, then the landslide phenomena occur here very high frequency and serious.

In order to reduce the landslide disaster which occurs in the area along the artery such as national roads, it is important to clarify the distribution of landslide topographic features. However, is too small, or the accuracy of a topographical map is not sometimes necessarily suitable. As mentioned above, taking an aerial photo newly in Vietnam was not necessarily easy and very big cost may start. In addition, aerial photographs of the mountain region taken in the past in Vietnam were on a scale of about 1:33,000, clarifying that they were unsuitable for the recognition of micro landforms from them. While, the availability of the picture of millions of sheets which ALOS photoed, 5 m mesh DSM (ALOS W3Ddata) and ortho data in the world are fixed, and it can easy purchase now. We tried the trial landslide topography mapping along the NH7 using ALOS W3D data. Based on the DSM data can easily be created from photos of ALOS W3Ddata, the contour line in 5 m interval and the topographical maps of the NH7 of central Vietnam were created. The landslide topographic features by deciphering the contour line of this topographical map have been implemented. Final, the checking and verify the result by field investigation is necessary. At three sites, remarkable topography condition changes were observed in a field survey. Local information around the sites (topography and geology, and characteristics of condition changes) and correspondence with landslide topographic information using W3D data were investigated in this study. As the result of the study, the landslide distribution maps is established along the National Road No. 7 is completed based on the ALOS W3D data and more than 1000 landslide areas are identified (Dung et al, 2016). Results also demonstrate that information equally matched with verification by field survey can be prepared.

Next, to identify the reality slip surface and clarify the characteristic of soil strength is one of the most fundamental technical matter for recognizing the mechanism and estimate the slope movement. We discussed and tried to build a Landslide Field Investigation Sheet (LFIS), that suitable for investigating the small-scale landslide occurs along transport arteries. A series of field investigations were carried along HCMR in Central during 2010 to 2016. Photos taken and sketched of 33 case studies of small scales of landslides along this route were carried in the field. Most important information on the site will be investigated and collected such as the topography features, geology characteristics and the deformation of landform. Based on this information, we try to classify the landslide types in groups of geology types, assessing the level of weathered of rocks on the slope and relationships between the soils and forms of landslides in the area. The results are as follow. 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. It is often the case that 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. Granitic rocks slide as rock falls of granite core stones formed at shallow layers by weathering and as rotational slides where deep layers are weathered.

Deduce the slip surface of landslide have been carried at outcrops by discussion and field test. The field test to clarify the slip surface and characteristics of rocks on the slope. In addition, one of the main targets of landslide mechanism analysis in the humid tropical strongly weathered zone is characterized the residual strength of weathered rocks. We are accumulating the field data and tried the soil strength testing. The soil samples were collected for ring shear test, X-ray diffraction analysis, and physical properties of rocks at the laboratory. The results from the study showed less hardness points at the around the slip surfaces. The mineral composition and physical characteristics differ depending on the geologic age, degrees of weathering and that their residual strength changes similarly. Especially, younger strata have a smaller angle of residual shearing resistance. The kaolin appears at heavily weathered rock instead of illite only contained in the fresh rock. High-plasticity clays with high clay content, high plasticity index, and high liquid limit have a smaller angle of residual shearing resistance and that soils of young geologic age contain swellable clay minerals and produce high-plasticity clays.

The next study is using the simulation of the slip surface on the contour from W3D data and result of soil tested for safety factor evaluation. Cases study in a typical landslide at NH6, NH7 and along HCMR. From outcomes of RBSM (Rigid Bodies-Spring Model) and FEM (Finite Element Method) analyses, we judge if the movement of a landslide mass can be mimicked in a laboratory. The study is conducted to find material characteristics of landslide mass in strong weathered and the saturated environment in the tropical country. In this study, each parameter which characterizes landslides is used to establish mechanical models of the landslide. Also, the parameters are used for a slope stability analysis, RBSM and FEM. In addition, we try to simulate the rainfall-penetration process from groundwater response. For this purpose, weathering properties of landslide materials should be comprehended qualitatively and classified.

Final, the landslide risk evaluation and proposed the new framework of landslide investigation and the management for landslide disaster prevention, mitigation and the control. Landslide risk evaluation by AHP approach (Saaty, 1980) has been carried a long time in Japan by Japanese scientists (Miyagi et al, 2004). But in Vietnam, this method is still fairly new. The question is how application this method in Vietnam? Japanese experts and engineers Vietnam have discussed and agreed to that could apply in Vietnam but need to consider characteristics of the landslide in Vietnam. Then based on the discussion and the cross-check the sheet, the AHP sheet was a bit modification, and the no necessity of geological factors contribution is also confirmed. The combination works with contour from W3D data, field investigation data, simulation and risk evaluation lead us the presence of real phenomena and will suggest the alternative countermeasure strategy setting up. The final, a new framework total management will be proposed for landslide disaster reduction in Vietnam.

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CHAPTER 1. SIGNIFICANTION OF THE RESEARCH

1.1 Vulnerability to natural disasters in Vietnam

Located in the Asia Pacific Region, the territory of Vietnam runs along longitude, with latitude from $8^{o}30'$ North to $23^{o}022'$ North and longitude from $102^{o}10'$ East to $109^{o}21'$ East. Vietnam's area is about 331,212 square km. Three quarters of Vietnam's territory is mountainous and nearly 3260 km of coastline are identified as one of the most exposed countries in the world with many natural disasters, including typhoons and tropical depressions (tropical storms), floods, landslides, and droughts. A 2007 assessment of the World Bank listed Vietnam as one of the five worst affected countries by climate change (The World Bank, 2009).

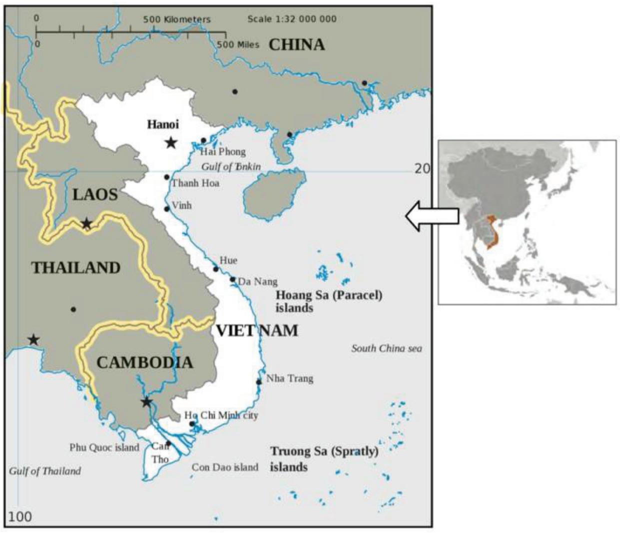

Fig. 1. 1 Location map of Vietnam

When calculating the total damage caused by two or more disasters, Vietnam ranks seventh out of 75 countries that suffer most from GDP. Accordingly, the percentage of total area at risk is 33.2%, the percentage of the population in the area affected by the risk is 75.7%, and the percentage of GDP in the risk area is 89.4% (The World Bank, 2005).

Natural disasters cause an average of 750 deaths and economic losses equivalent to 1.5% of GDP each year. However, damage and loss data is chronically underreported, so real totals may be much higher (The World Bank, 2009). Over the period of 2002 and 2006, disasters have killed about 1,700 people and physical damage is estimated at 4.69 billion dollars (The UNDP, 2015). Most serious natural disasters in Vietnam are related to water, such as typhoons, flood, flash flood, landslide, drought and coastal erosion. These natural disaster risks are generally classified as Table 1.1 (The JICA, 2015). The records of natural disasters that have affected Vietnam are classified based on the impact and frequency of occurrence in Fig 1.2. Both "damage amount" and "number of deaths" are used to express the impact, and "number of disasters occurred between 1983 and 2012" is used to represent the frequency of occurrence (The JICA, 2015).

Tab. 1. 1 Natural Disaster Risks and Frequency in Vietnam

High	Medium	Low
Flood	Hail rain/tornado	Earthquake
Typhoon	Drought	Accident (technology)
Inundation	Landslide	Frost
	Flash flood	Damaging cold
	Fire	Deforestation

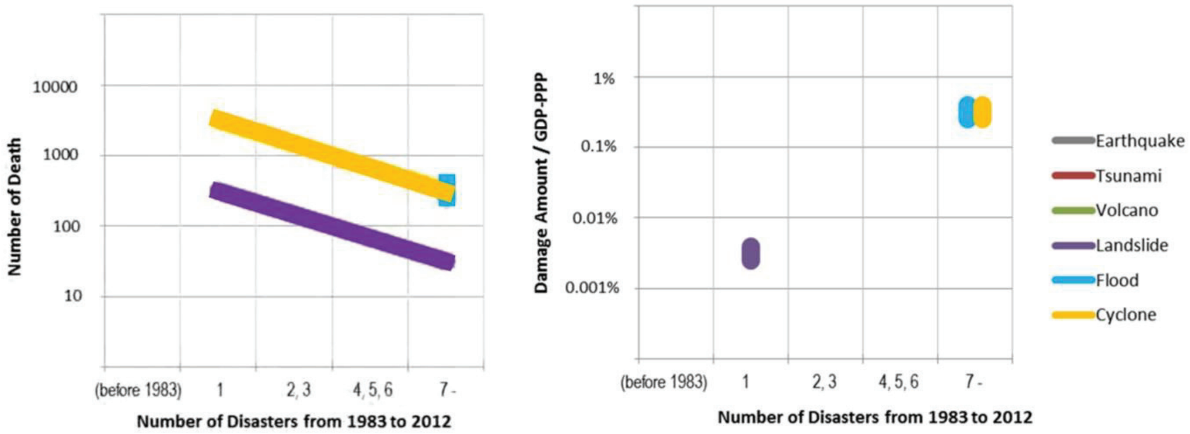

Fig. 1. 2 Impacts of Natural Hazards in Vietnam (Left: Number of Death and Right: Damage Amount)

Viet Nam suffers from 5 to 7 typhoons annually and most typhoons and tropical depressions happen between July and November. In the last 50 years, about 20,000 people have been killed by typhoons, compared to only 4,000 for floods. Over this century, the worst typhoons were in 1964 typhoon that caused 7,000 casualties and Linda typhoon in 1997 (WHO in Vietnam). Linda typhoon is also known as the fifth strongest storms in 100 years, appeared quite late in the South China Sea, hit suddenly with a high intensity to a small part of Binh Thuan to Ca Mau in the South, a region without storms in hundreds of years. Because of completely passive for respond, so that over 4,500 dead and missing people, mainly fishermen, more than 3,500 fishing boats, more than 200,000 houses, 325,000 hectares of rice and crops were damaged, this was estimated equivalent to $US600 million (Central Meteorological Forecast Center of Vietnam). The storm caused almost in comparison with the biggest storm in the history of Japan in 1959, internationally known as Vera or Isewan Storm, killed 4,697 people, lost 401 people and injured 38,921 people. The physical damage is about $US600 million (National Institute Informatics, Japan). The damages caused by typhoons in Vietnam from 1990 to 2012 are shown in Table 1.2.

Floods are the most common disaster in Vietnam, caused by typhoons, heavy rains, and rising sea level. Therefore, whenever a typhoon is approaching, a flood warning is often issued as these types of floods tend to occur quickly (The World Bank, 2009).

Typhoons and Floods (including flash flood and landslides by heavy rains) accounted for 87% of the disasters that occurred between 1980 and 2010, caused 100% of the dead. In more than 50 years (1954-2006), there were 380 typhoons and tropical depressions hit to Vietnam (The World Bank, 2009).

Drought ranks the third in frequency of natural disasters in Viet Nam, most concentrated in the Red River Delta in the North and the highland region in the South West.

Landslides, flash floods, and mud floods are usually caused by concentrating heavy rains combining with weak geological structure and human impacts like mountain destruction of roads, forest destruction, etc., that cause serious damage to the human life, property and the ecological environment, especially along transport arteries of the new traffic routes have been being built and reconstructed. Mountainous are particularly at risk of flash floods, mud floods, and landslides. The annual volume of landslides in Vietnam is hundreds of thousands of cubic meters, not only damaging buildings and roads, but also causing hundreds of millions of US dollars damage each year (Tam, 2001). In addition to this, it killed about 30 people each year (Ly, 2011).

Beside storms, floods, landslides are widespread and the most serious damage, other natural disasters such as river flooding from upstream, river erosion, shoreline and earthquakes also occur in parts of Vietnam. River flooding from upstream, river erosion, shoreline occurs seriously in the Mekong Delta area in the Southern part of Vietnam. The whole territory can be divided into five zones of hazard risk as Table 1.3 (Vietnam Disaster Management Unit, 1996).

Tab. 1. 2 Damages caused by typhoons in Vietnam from 1990 to 2012 (The World Bank, 2009)

Years1990 – 1999											
Damaged	**Unit**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Dead -including missing	(person)	63	38	142	221	31	91	201	2951	317	37
Injured	(person)	569	22	38	498	14	180	670	1298	93	0
Volume of landslides	(10^4m3)	161.26	1.75	103.01	21.35	65.07	145.52	540.01	529.76	787.48	118.87
Years 1999– 2012											
Damaged	**Unit**	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2012**
Deaths - including missing	(person)	39	34	8	53	62	455	183	134	317	7
Injured	(person)	111	185	33	22	120	1549	303	21	1310	1
Volume of landslides	(10^4m3)	129.82	92.77	3.10	27.00	312.31	169.78	462.32	153.68	1153.01	2.30

Note: In 2002, 2010, 2011 there are no data

Tab. 1. 3 Hazard zones of Vietnam

Disaster zone	Principle water hazards
Northern Mountain	Flash floods; landslides
Red River Delta	Monsoon river floods; typhoons
Central Provinces	Typhoon storms; flash floods
Central Highlands	Flash floods; landslides
Mekong Delta	River flooding from upstream; typhoons

Tab. 1. 4 Historical natural disaster damage in Vietnam, from 1989-Jun. 2017 (modified from WHO)

Year	Deaths and missing	Injured	People affected	Number of Houses destroyed	Number of rooms in Schools destroyed	Number of Hospitals destroyed	Area of rice field damaged (ha)	Landslides in Irrigation (m^3)	Landslides in Transportation (m^3)	Area of ponds, lakes, lagoons Damaged (ha)	Total estimated damage $US (,000)
1989	959	1,359	5,635,000	235.729	10.4	1.76	765.375	8.495.526	1.819.861	479	21,000
1990	384	308	510,000	14.521	1.931	423	237.8	5.930.817	2.047.067	684	725
1991	492	236	316,478	15.063	383	53	211.377	920.48	401.79	936	57,200
1992	332	33	178,234	8.211	313	45	366.572	4.460.705	2.016.335	29.13	66,100
1993	347	52	41,520	29.47	1.462	29	171.56	3.216.396	858.914	7.664,4	75,000
1994	507	34	393,000	7.302	9.84	23	658.676	21.195.929	914.753	6.44	253,300
1995	351	51	423,000	11.043	1.161	26	198.439	7.637.489	3.271.918	4.41	107,200
1996	1128	591	1,051,206	96.927	5.297	200	927.506	59.668.186	6.879.992	70.991	751,420
1997	3,692	907	3,697,225	111.037	1.714	86	641.393	4.684.519	1.795.052	138.331	887,000
1998	647	97	2,520,665	13.495	563	5	195.661	5.460.263	3.562.284	7.616	121,900
1999	825	576	7,039,150	52.585	726	95	131.267	14.795.275	111.704.16	42.903	309,500
2000	762	215	5,027,505	12.253	140	47	655.403	29.249.495	1.219.387	21.25	291,035
2001	604	95	1,785,895	10.503	151	28	132.755	1.195.524	970.149	16.615	171,900
2002	355	116	2,733,500	9.802	77	2	46.49	115.332	947.601	5.828	284,200
2003	180	81	402,946	4.487	49	1	209.764	2.200.097	2.752.120	14.49	105,000
2004		23	535,951	4,766							38,000
2005	377	31	851,900	7.586	258	198	504.098	2.987.876	3.417.238	55.691	346,370
2006	579	2,010	2,994,720	74.783	268	25	139.231	1.053.377	1.636.560	9.819	1,099,000
2007	462	322	1,599,755	9.908	1.304	52	173.83	4.834.057	7.126.064	19.765	981,000
2008	474	163	776,330	5.18	138	6	146.945	2.743.835	4.728.829	57.199	673,500
2009	435	1,006	3,607,820	13.354	1.364	7	237.799	3.033.202	10.321.193	9.424	1,065,200
2010	355	103	1,522,710	2.6			30				704,700
2011	257	2		1.2			330				92,300
2012	269			2.6			272000				800,000
2013	313			6.401			122000				1,500,000
2014	133	145		42.758			230.086				128,636
2015	154	127		1.242			445.000				368,818
2016	264	431		5.431			828.661				1,720,000
Jal. - Jun. 2017	27	30					3,800				19,681

1.2 The status of Landslide in Vietnam

Based on a combination of the model couples precipitation data (from the Global Precipitation Measurement (GPM) mission) with data about features that contribute to landslides such as, deforestation, fault lines, and bedrock and slope stability, the NASA has developed a global landslide susceptibility model that updates every thirty minutes. The model uses satellite imagery and remotely sensed data to compile a worldwide view of landslide potential that can be used for disaster planning. According to this map, Vietnam has a large part of its territory that is in the risk area of the landslide from moderate to severe, mainly concentrated in Northern, the Central, and Central Highland areas (Fig 1.3).

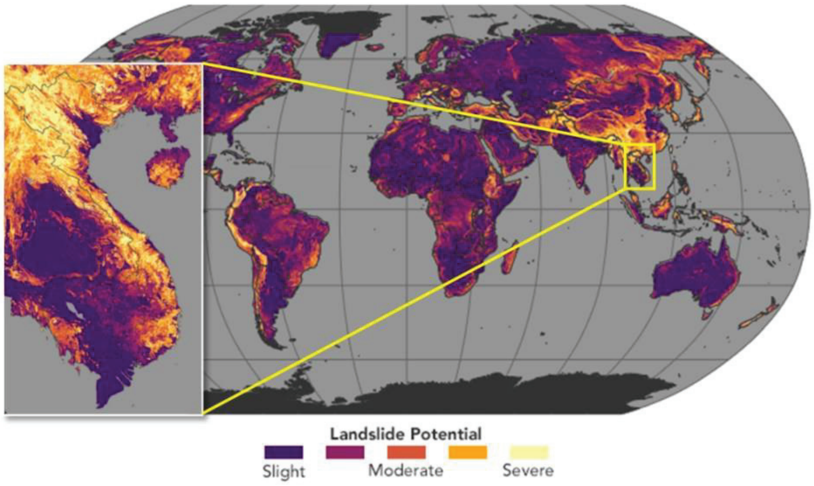

Fig. 1. 3 Assessing landslide potential map in the world and in Vietnam (by NASA)

According to The Landslide Risk Map of Vietnam by Yem N. et al,. (2006), the high-risk landslides occur mainly in mountainous areas (Fig 1.4). In the delta-hill area, landslide risk is low, while the delta area is almost there are no landslides. The distribution of the landslides also mainly concentrated in the northern mountainous region (Northeast, Northwest), the Central and Tay Nguyen region. On the other hand, landslide developments are also very different in the mountain region. It depends on the difference of three main decisive factors underlying groups. Those are geology (the type of rocks, shell types weathering, the hydrogeological conditions, the level of development of the lineament, the active fault zone, etc.), geomorphology (slope angles, the deep and horizontal cleavage, etc.) and climatic conditions (rain).

In the Northern mountainous, there is over half of the total area with high and very high risk of landslides. The distribution is also mainly concentrated in the northwest. The more down to the southeast, the distributions and landslide risk is lower. In the northeast mountainous area, the risk of landslides remains high and distribution concentrated in Lo Gam area and Hoang Su Phi mountain range.

The result of a landslide investigation project in 10 provinces of the Northern mountainous region by Vietnam Institute of Geosciences and Mineral Resources (VIGMR) in two years 2012 and 2013, there were 9201 landslides and mainly concentrating in the mountains of the Northwest areas. Most of the landslides occurred in small and medium scale (the volume is smaller than 1000m^3), occupy 82.82% of the total landslides. The large scale is 16% and very large scale for only 1.18% (Fig 1.5). Besides of landslides, there were 279 points of flash floods and debris flows have been recorded in these areas.

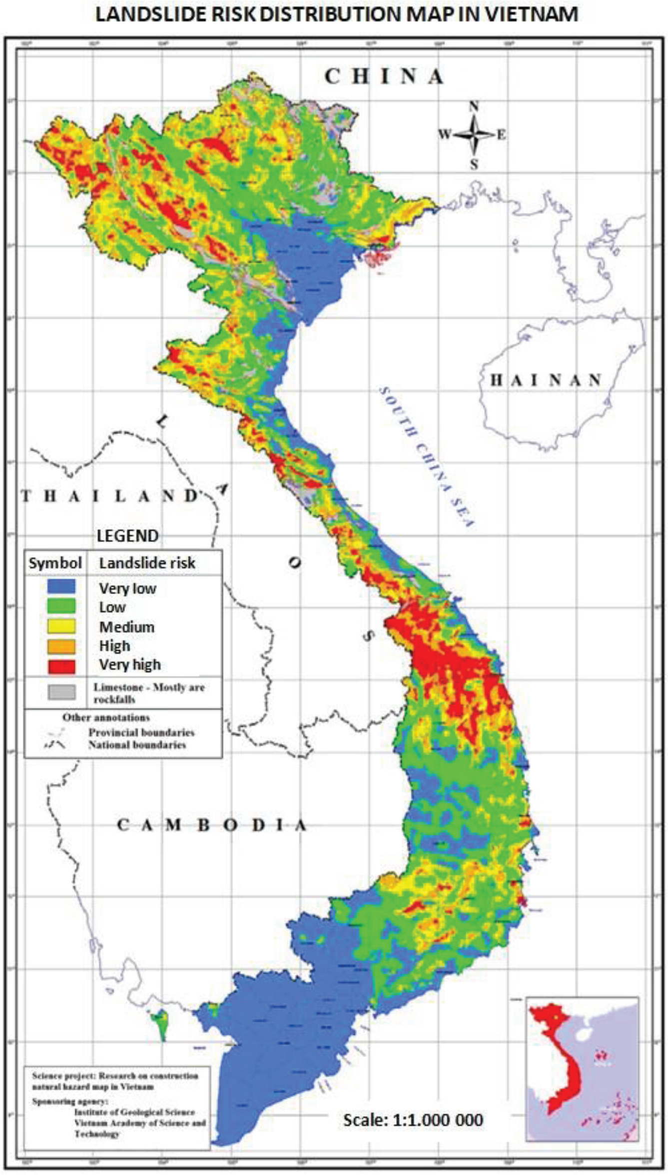

Fig. 1. 4 Landslides risk map of Vietnam (N. Yem et al,. 2006)

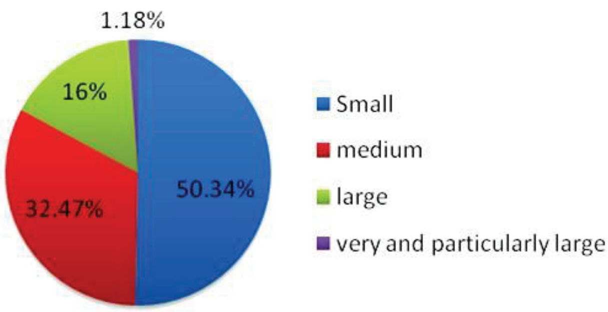

Fig. 1. 5 Landslide classified by volume in 10 Northern provinces

In mountainous areas of the Central, from Phong Nha in Quang Binh to the North, landslides risk in an average level and mainly concentrates in mountainous areas of Nghe An and Thanh Hoa provinces. In the meanwhile, from Phong Nha down to Thua Thien Hue, Quang Tri, and Kontum provinces, landslides are concentrated and at the high risk. These areas are considered as one of the most sensitive areas and at higher risk of landslides in Vietnam. Particularly in Quang Nam province area, the average density is 5 sliding blocks per 100 square km. In the areas of the districts as Tay Giang, Dong Giang, Duy Xuyen, Dai Loc, Tien Phuoc, Phu Ninh, the density of landslides is 15 to 20 sliding blocks per 100 square km. In the areas like Nam Giang, Hiep Duc, Bac Tra My and Phuoc Son, the density is lower, ranging from 10 to 15 sliding blocks per 100 square km. There are 49.5% of sliding blocks is large scale, while the type of small-scale is only 19.9% of the total (Hung P.V., 2011).

In the Southern - central mountains, landslide risk is at the high levels and concentrates mainly in the Northern of Nghia Binh range. The mountainous area of Phu Yen in Khanh Hoa province, landslide risk is on the average level and in northern Phu Yen, the landslide risk is on the low level.

In the Southern part of the Central Highlands, landslides are at the high risk and concentrate in three adjacent areas as DiangDia, ChuYangSin, and Dalat. Meanwhile, in the DiLinh's mountain and Dak Nong areas are at the average risk of landslides. In the remaining areas of the Central Highlands, topography mostly is plateaus and valleys, the distribution and risk of the landslide are low and very low.

Fig. 1.6 to Fig. 1.11 and Table 1.5 are photos and damage of severe landslides and debris flow recorded in recent years.

Fig. 1. 6 Landslide in Bat Xat district, Lao Cai province. *(dantri.com.vn)*

Fig. 1. 7 Landslide in La Pan Tan commune (Yen Bai province). *(HNMO)*

Fig. 1. 8 A landslide in Ha Long city, 9 people buried under hundreds of tons of rock *(zing.vn)*

Fig. 1. 9 Heavy rain causes landslide, prolonged congestion in NH4B - left *(vnntimes)*

and Rockfalls on NH No.1 - right *(vnntimes)*

Fig. 1. 10 Landslide on NH8A caused stuck more than one day crossing the Cau Treo border *(dantri)*

and (right) Landslides on NH6 causing prolonged congestion *(24h.com.vn)*

Fig. 1. 11 Landslide at Phan Me coal mine (Thai Nguyen province) killed 7 people

Tab. 1. 5 Recent recorded severe landslides and debris flow in Vietnam

Location	Date	Type	No. of Deaths and missing	Damaged
Nam Cuong, Cho Don (Bac Kan province)	23rd Jul. 1986	Debris Flow & Landslides	7	120 ha rice fields, 20 km of roads
Lai Chau town	27th Jun. 1990	Debris Flow & Landslides	Over 100	607 houses, 5 bridges, 10km2 of town demolished
Nam Muc & Muong Lay (Lai Chau province)	17th Jul. 1994	Debris Flow & Landslides	20	
Muong Lay town (Lai Chau province)	17th Aug. 1996	Debris Flow & Landslides	55	The commune had to move to another place
Highway No. 27 (Lam Dong province)	l0th Oct. 2000	Debris Flow & Landslides		37 severe landslides in 55km, 500m highway fully destroyed
Sa Pa district in Lao Cai province	15th Jul. 2000	Debris Flow & Landslides	20	25 people Injured
Nam Coong, Nam Cuoi, Sin Ho district, Lai Chau province	3rd Oct. 2000	Debris Flow & Landslides	39	18 people Injured
Yaly hydropower plant (Kon Tum province)	since 2002	Landslide		causing damage of billions of VND each year
Bac Quang and Xin Man districts, Ha Giang province	16th Aug. 2002	Flash Flood & Landslides	25	17 people Injured
Huong Son, Huong Khe and Vu Quang districts, HaTinh province	20th Sep. 2002	Flash Flood & Landslides	83	117 people Injured

Du Tien & Du Gia, Yen Minh (Ha Giang province), Bao Lam Cao Bang province	19th Jul. 2004	Flash Flood & Landslides	56	33 houses, 627 ha of rice fields
Sung Hoang (Phin Ngan, Bat Xat, Lao Cai province)	13th Sep. 2004	Flash Flood & Landslides	23	4 houses destroyed
Quang Ninh, Yen Bai, Nghe An provinces	28th Sep. 2005	Flash Flood & Landslides	96	17 people Injured, Cat Thinh commune and Nghia Lo town were severely damaged
Bat Xat, Sa Pa, BaoThang, Bao Yen (Lao Cai province)	09th Aug. 2008	Landslide	65	Many communes were destroyed
Lao Cai, Yen Bai, Son La, Lang Son, Ha Giang, Cao Bang, Quang Ninh, Bac Giang provinces	2008	Flash Flood & Landslides	246	> 200 people Injured
Pac Nam, Bac Kan province	2009		13	5 people Injured
Quang Nam, Quang Ngai, Binh Dinh , Phu Yen, Kon Tom, Gia Lai, Dak Lak provinces	2009	Flood and Flash Flood & Landslides	266	1146 people Injured
Thanh Hoa, Nghe An province	Sep. 2011		6	
Phieng Sa, Tan Son (Hoa Binh province)	16th Feb. 2012	Landslide	6	Destroyed a section of road on NH6
Tong Dau and Dong Ban (Hoa Binh province)	2nd Mar. 2012	Road failures		Destroyed more than 100m of the road and caused serious traffic problem
Mountainous northern province of Yen Bai	7th Sep. 2012	Landslide	29	Coffee plantation affected by landslides
Sa Pa district in Lao Cai province	6th Sep. 2013	Landslide	21	Heavy rain over the last three days, flash floods sent rocks and soil crashing into a rural village
Quang Nam and Binh Dinh provinces	15th Nov. 2013	Landslide	14	
Ban Khoang, Sa Pa district in Lao Cai province	5th Sep. 2013	Flash Flood & Landslides	11	16 people Injured

1.3. Research Experiences

Hereafter, I would like to explain my personal research background for the deeply easy understanding of the thesis extraction.

After graduating from the Civil Engineering University of Vietnam in 2004, I was employed to work as a surveyor/designer/researcher for traffic construction by Institute of Transport Science and Technology (ITST), Ministry of Transport of Vietnam.

During that time, I had experience in Civil engineering research, directly performed the survey, carried out project feasibility, designed traffic safety audit and managed of transportation construction projects, including large-scale civil and highway projects of going through the mountainous terrain.

In the processing of research and development, there were many problems of construction works related to the stabilization of embankment paths passing through the soft ground, and failures on the slope of the cutting-slope, which required treatment. From the research experience to design options for handling these projects, I was particularly interested in road slope protection works and landslide field.

That is a reason for my master thesis entitled "Researching the mechanics of erosion phenomena on the surface of highway slope caused by rainfall and proposed solution for treatment -Case study on Truong Son Dong highway" (2011), which is also a part of my research related to road slope protection works and landslide field.

1.3.1 Civil Engineering Works

In the field of civil engineering, I had five reports in the Vietnamese language related to construction works quality management, experimental and traffic safety. Please refer from List of all study reports (item 1.3.3) from (No.16) to (No. 20). For more concretely, I would like to mention as followings:

For construction works quality management, I have two reports. One of them involved Applied Science and Technology to enhance Supervision Consultant activity quality and Transport construction works quality (Report No. 17) in 2014, which was published in Proceedings of Symposium ITST. One report (Report No. 20) in 2016, involved incidents occurred while constructing Da Nang - Quang Ngai expressway in Central of Vietnam, titled "The proposed solutions to limit the impact of the phenomenon of cracking in cement treated aggregate bases after the construction of Da Nang-Quang Ngai expressway project".

In the field of experimental working, I have a research project of Ministry of Transport in 2015 for Vietnamese standard. This report (Report No. 16) named is "Hot Mix Asphalt Concrete- Method of Test for Coarse Aggregate Angularity", specifies the method of test for coarse aggregate angularity using the porosity value of the aggregate in the loose state.

Finally, in the field of traffic safety, I have two reports involved two research projects of Ministry of Transport. The first report (Report No. 18) was "Research establishes quality criteria system for flexible pavement of highway in Vietnam" (2010-2011), and the second (Report No. 19) was "Research on demarcation criteria and effect limit of densely populated and urban areas along highways in order to propose modification of signal forms and plug locations of traffic signs to enhance traffic safety" in 2011.

1.3.2 Some Landslide Research References before the Doctoral Dissertation

The first published (Report No. 15) is a master thesis, which researches on the phenomenon of slope failures along the road due to erosion reason. The idea starts from a fact of exploitation and maintenance of roads in Vietnam, the erosion often creates gully, channels, and caves on the surface of the slope, which has a great impact on the overall stability of the roadbed and the quality of the road. That is one of the most common phenomena occurs on the slope surface of many routes, particularly in the rainy seasons. This problem has been mentioned, many solutions have also been applied. However, that seems to be not effective, many cases even counterproductive that continues to cause the instability of the roadbed. The study purpose clarified the mechanism and cause of the erosion phenomenon on slope surface, special in complex geological conditions, rocks on the slope are easy to disintegrate when encountering water. Based on the result of the study, a series solution has been proposed to minimize the impact of erosion on the overall stability of the roadbed slope in accordance with economic and technical conditions in Vietnam.

The next research belongs to a program of cooperation between the Ministry of Transport and Ministry of Science and Technology in the field of traffic safety and landslide prevention (Report No. 14). The urgent work to research is to evaluate the landslide risk and find out how to mitigate the landslide phenomenon occurring on Ho Chi Minh route (HCMR). Since the road opened to national traffic system, hundreds of landslides have been occurring along the road in the rain-stormy seasons that have seriously destroyed the road and made traffic congestion for several days. This task is assigned a group of engineers and scientists of ITST, in which I am a member. The main outputs of the project include: (1) Building up Landslide Basic Data (LBD) of occurring along the corridor of HCMR as the basic data for research; (2) Creating the method landslide susceptibility based on LBD and causative factors; (3) Making a landslide susceptibility map for Thanh My- Kham Duc section and (4) Propose the countermeasures for mitigation and protection.

For these purposes, a series of field investigations along the HCMR were conducted by the research team. There were 548 landslide locations recorded at that time. The characteristics of landslide such as the spatial relationship between the landslide and the road, signs and causative factors from the field observed have been recognized on site. However, due to lack of the knowledge and experience of landslide investigation, the micro-features did not particularly describe. Landslides were classified by Vietnamese National Standard, which divided into four categories: shallow landslide (55%), deep landslides (32%), erosion and flow type landslide (12%) and rock fall (1%). However, this classification is still controversial.

The landslide causative factors were also considered and focused on four major groups: geomorphology-topography, geology, climate and human causes. 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) that are usually targets of the study. The important factors are selected for the landslide susceptibility mapping. Depending on the availability of the data, the factors are considered, including slope angle, weathering, geomorphology, fault density, geology, drainage distance, elevation, precipitation and land use.

The assessment of sensitivity map is conducted by experts with evaluating views using Analytic Hierarchy Process (AHP) algorithm. The landslide susceptibility is divided into low, medium, high and very high sensitive classes depending on the weight evaluation. However, the weight evaluation differs with no unified opinion from evaluators. As the result, there are 67% of landslides in the high and very high area of sensitive classification map.

The reports from No.1 to No.13 (except No.3) are conducted in the framework of The SATREPS project titled "Development of landslide risk assessment technology along transport arteries in Vietnam" by JICA/JST/ITST. A lot of knowledge and technology in the field of landslides have been introduced and transferred to young engineers of ITST. Based on obtaining knowledge and experience, research and application in Vietnam have been gradually carried out with the support of Japanese experts.

The reports No.6, No.8, No.11, No.12, and No.13 are submitted and accepted for Proceedings of the SATREPS Workshop on Landslides in Vietnam in July 2014 and October 2016 by ICL (ISBN: 978-4-9903382-2 and ISBN:978-4-9903382-3-7). Respectively, the report No.6 regards to the Integrated Approach of Landslide Hazard Mitigation along the roadside in Central Viet Nam. The report No.8 is regarded to Landslides mapping and susceptibility evaluation along HCMR and Hai Van area. The report No.11 is regarded to change the safety factors by the series of land deformation at a typical landslide along the national road NH6. The report No.12 regards to the Objective Function based on the AHP risk evaluation system in humid tropical regions. And, the report No.13 is regarded to Landslide mapping and the risk evaluation by Aerial photo Interpretation in Vietnam.

The two reports No.9 and No.10 are submitted and presented at the 2015 Landslide conference hold by the Japanese Landslide Association. They respectively concentrate on the topographic and geological features of landslides in Vietnam and a trial of risk evaluation based on the wide landslide topographic mapping in Vietnam.

The five reports No.1, No.2, No.4, No.5 and No.7 are respectively named as "The total management flow of landslide disaster risks along main roads in tropical mountain ranges - based on research accomplishments in Central Vietnam", "Residual strength characteristics of weathered rocks in humid tropical region - A case study in Central Vietnam", "The current manual and standards for the survey and design works for landslide prevention in Vietnam", "The trial of landslide topography mapping using W3D data – Case study along the National Road NH7 in Central Vietnam", and "The outline, typology and the causes of landslides disasters in Vietnam". These reports are implemented and presented in the special issue of Transactions, Geomorphological Union (vol.37-1 in January 2016 and vol.38-4 in 2017).

The report No.3 is a research project of MOT, which is conducted and expected to finish in early 2018, is named as "Research on the combination of aero photos analysis and the field investigation to select the solutions for mitigating disaster of landslides in Vietnam".

1.3.3 List of all Study Reports

1. Ngo Doan Dung, Toyohiko Miyagi, Eisaku Hamasaki, Tatsuya Shibasaki, Kazunori Hayashi, Dinh Van Tien, Le Hong Luong (2017): Total Management Flow of Landslide Disaster Risks along Main Roads in Tropical Mountain Ranges - Based on Research Accomplishments in Central Vietnam - Transactions Japanese Geomorphological Union, vol.38-4.

2. Ngo Doan Dung, Tatsuya Shibasaki, Toyohiko Miyagi, Eisaku Hamasaki (2017): Residual strength characteristics of weathered rocks in the humid tropic region - A case study in the central Vietnam - Transactions Japanese Geomorphological Union, vol.38-4.

3. Ngo Doan Dung et al.* (2016-2017): Researching on the combination of aero photos analysis and field investigation to select the solutions for mitigation disaster of landslides in Vietnam, Research project of Ministry of Transport (MOT). (are continuing and not finish yet, about 250 pages).

4. Ngo Doan Dung, Dinh Van Tien, Nguyen Xuan Khang (2016): The current manual and standards for the survey and design work for Landslide prevention in Vietnam - Transactions, Japanese Geomorphological Union, vol.37-1, pp. 5-31.

5. Ngo Doan Dung, Toyohiko Miyagi, L.H. Luong, Eisaku Hamasaki, Kazunori Hayashi, Dinh Van Tien (2016): Trial of landslide topography mapping using W3D data – Case study along the National Road No. 7 in central Vietnam. Transactions Japanese Geomorphological Union, vol.37-1.pp.127-140.

6. Ngo Doan Dung, Tatsuya Shibasaki, Eisaku Hamasaki, Toyohiko Miyagi (2016): The Integrated Approach of Landslide Hazard Mitigation along the Roadside in Central Viet Nam. Proceedings of the SATREPS Workshop on Landslides in Vietnam, pp. 134-141. (ISBN:978-4-9903382-3-7).

7. Tien Dinh Van, Shinro Abe, Ngo Doan Dung, Do Ngoc Ha, Toyohiko Miyagi (2016): Outline, typology and the causes of landslide disasters in Vietnam. Transactions Japanese Geomorphological Union, vol.37-1.pp.41-56.

8. Miyagi Toyohiko, Dinh Van Tien, Ngo Doan Dung (2016): Landslide mapping and susceptibility evaluation along Ho Chi Minh route and Hai Van area. Proceedings of the SATREPS Workshop on Landslides in Vietnam. pp. 10-18; (ISBN:978-4-9903382-3-7).

9. Ngo Doan Dung, Dinh Van Tien, Shinro Abe, Do Ngoc Trung, Toyohiko Miyagi (2015): Topographical and Geological feature of Landslide in Vietnam. Abstract of the 54nd annual meeting of the Japan Landslide Society - (2.5).

10. Miyagi Toyohiko, Shinro Abe, Eisaku Hamasaki, Hiromu Daimaru, Tatsuya Shibasaki, K.Hayashi, Tien Dinh Van, Le Hong Luong, Ngo Doan Dung (2015): Current Study of the Landslide Risk Evaluation in Deep Weathering Region - A Trial of Risk Evaluation base on wide Landslide Topography Mapping in Vietnam -. Abstracts of the 54th annual meeting of the Japan Landslide Society - (2.4).

11. Ngo Doan Dung, Eisaku Hamasaki, Tatsuya Shibasaki, Toyohiko Miyagi Hiromu

Daimaru, Tien D. V., Le Hong Luong (2014): 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. pp. 119-122; (ISBN: 978-4-9903382-2-0).

12. Eisaku Hamasaki, Toyohiko Miyagi, Tien D. V., Ngo Doan Dung (2014): Objective Function based AHP Risk Evaluation System in Humid Tropical Regions. Proceedings of the SATREPS Workshop on Landslides in Vietnam. pp. 123-127; (ISBN:978-4-9903382-2-0).

13. Miyagi Toyohiko, Hamasaki Eisaku, Dinh Van Tien, Le Hong Luong, Ngo Doan Dung (2014): Landslide mapping and the risk evaluation by aerial photo interpretation in Vietnam. Proceedings of the SATREPS Workshop on Landslides in Vietnam. pp. 87-95, (ISBN:978-4-9903382-2-0).

14. Tien Dinh Van*, Ngo Doan Dung et al. (2011): Landslides Susceptibility Map for Ho Chi Minh Route (NgheAn - KonTum Section). A research project of Ministry of Transport (MOT), Code: DT012016. pp 8-273.

15. Ngo Doan Dung* (2011): Researching the mechanics of erosion phenomena on the surface of highway slope caused by rainfall and proposed solution for treatment - The case study on Truong Son Dong highway-. Master's Dissertation, University of Communication and Transportation. pp 1-144.

16. Bui Ngoc Hung*, Ngo Doan Dung et al. (2015): Hot Mix Asphalt Concrete-Method of Test for Coarse Aggregate Angularity-. A research project of Ministry of Transport (MOT), Code: TC1521. pp 1-15.

17. Nguyen Xuan Khang*, Ngo Doan Dung (2014): Applied Science and Technology to enhance Supervision Consultant activity quality and Transport construction work's quality, Proceedings of Symposium ITST. pp 1-8.

18. Doan Minh Tam*, Ngo Doan Dung et al. (2010-2011): Research establishes quality criteria system for flexible pavement of highway in Vietnam. A research project of Ministry of Transport (MOT), Code: DT103012. pp 17-397.

19. Nguyen Manh Hung*, Ngo Doan Dung et al. (2011): Research on demarcation criteria and effect limit of densely populated and urban areas along highways in order to propose a modification of signal forms and plug locations of traffic signs to enhance traffic safety. A research project of Ministry of Transport (MOT), Code: DT113022. pp 10-297.

20. Pham Thanh Long*, Ngo Doan Dung, Le Minh Tu (2016): The proposed solutions to limit the impact of the phenomenon of cracking in cement treated aggregate bases after construction of Da Nang-Quang Ngai expressway project. Abstracts of the Young Scientists in Transport sector Workshop, Hanoi, pp.229.

Note: *The publications were written in Vietnamese.

1.4 The research Issues

The landslide phenomenon is the cause of economic damages up to 0.1 % of total GDP and about 30 persons fatal every year in Vietnam. However, it can easily recognize that control and mitigation of damages caused by landslides current in Vietnam seem to be quite difficult and passive. The main reasons are lack and limited in guidelines and standards for field survey, collecting soil data, simulation and calculate the safety factor, countermeasures. In addition, lack of professional engineers and the budget for landslides, lack of forecasting technology and awareness of local people are also reasons.

The issues that I studied concerning to landslide mapping, field survey, collecting soil data, simulation and calculate the safety factor of slopes. Based on this studied, I propose a management system of landslide disaster risks along the main road in tropical mountain ranges and might be applied to all of Southeast Asia as a humid tropical zone. These are discussed as follows.

1.4.1 The current manual and standards for the survey and design work for Landslide prevention in Vietnam (Transactions Japanese Geomorphological Union, vol.38-4)

Report No.4

This paper presents the current situation of manual and standards for the survey and design works for Landslide prevention in Vietnam. 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 along roadsides such as National highway NH1, NH6, NH7, NH37, and HCMR, etc., it is able to be recognized that the responding in the face to this dangerous phenomenon seems to be quite passive. Although the Vietnam government has made from the overall to detail strategies to deal with natural disasters, because Vietnam still lacks experts with experience in the face of the phenomenon of landslides so working handling results are still limited. In particular, one of the root causes of this problem is the lack of documentation, technological processes, and standards for surveying, designing handling landslide prevention works. Meanwhile, the Vietnam current standards in this area are limited in content and shortcomings when used.

The continuing to update and supplement to finishing standards on survey and design as analyzed above to keep up with advanced scientific technology in the world and application, improve the efficiency of prevention and minimize the risks caused by landslides in Vietnam is currently essential.

1.4.2 Trial of landslide topography mapping using W3D data – Case study along the National Road No. 7 in central Vietnam (Transactions Japanese Geomorphological Union, vol.38-4)

Report No.5

In order to reduce the landslide disaster which occurs in the area along the artery such as national roads, it is important to clarify the distribution of landslide topographic features. However, is too small, or the accuracy of a topographical map is not sometimes necessarily suitable. Moreover, when taking an aerial photo newly, very big cost may start. There are never many countries which an aerial photo is taken repeatedly and it can purchase freely and cheaply at a rate once in ten years like Japan.

From 2015, based on the picture of millions of sheets which ALOS photoed, 5m mesh DSM (ALOS W3Ddata) and ortho data in the world are fixed, and it can purchase now. Then, for the National Route 7 of central Vietnam, the contour line was created from the DSM data and the topographical map was created. We decided to find out landslide topographic features by deciphering the contour line of this topographical map. As a result, 1000 or more landslide topographic features were able to be checked. It will be evaluated what kind of potential disaster vulnerability this landslide feature will have from now on.

This paper presents an investigation of the distribution of landslide topography over the area along National Road 7, which runs from Vinh city located at the northernmost end in central Vietnam to the Laos border via Nghe An Province. The novelty of this study is that analyses have been conducted based on digital surface model (DSM) data (W3D data) of a 5-m grid, with orthographic images created from image data acquired from ALOS. This strategy was undertaken because of huge costs and effort necessary for newly acquiring aerial photographs. Accordingly, an objective of this study is an evaluation of the validity of using these DSM data for the mapping of landslide topography.

1.4.3 Residual strength characteristics of weathered rocks in humid tropic region - A case study in the central Vietnam (Transactions, Japanese Geomorphological Union, Vol. 38-4)

Report No.2

Residual strength of weathered rocks at the slip surface zone is an important parameter for evaluating the reactivation potential and understanding the progressive failure mechanism. The combined study such as soil residual strength, micro-landform measurements, mapping and three-dimensional safety ratio calculations lead the changing processes of landslide risk. In this study, a series of experimentation has been performed with soil sample in humid tropical region from the apparent slip surface at landslide along the Ho Chi Minh route in the Central Vietnam. The residual strength was measured using a Bishop-type ring shear tester in a draining condition. The soil hardness is examined by Yamanaka-type hardness tester at the sites. The grain size test, liquid limit test, plastic limit test, X-ray diffraction analysis, and box shear tests were carried at the laboratory.

The data from the study showed fewer hardness points at the around the slip surfaces. The mineral composition and physical characteristics differ depending on the geologic age and degrees of weathering and that their residual strength changes similarly. Especially, younger strata have a smaller angle of residual shearing resistance. The kaolin appears at heavily weathered rock instead of illite only contained in fresh rock. High-plasticity clays with high clay content, high plasticity index, and high liquid limit have a smaller angle of residual shearing resistance and that the soils of young geologic age contain swellable clay minerals and produce high-plasticity clays.

1.4.4 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, ISBN: 978-4-9903382-2-0)

Report No.11

This paper presents an example of the landslide in the National Route 6 of the Hanoi suburbs, near Hoa Binh province. Although this landslide is not huge, the state immediately after disaster generating is indicated comparatively in detail. Moreover, an understanding is also advancing a series of field survey. The current field investigations are, make up the micro landform classification map for the realization the slope movement tendency, clarify the geological structure and soil strength, and landslide topography measurement by laser survey. Based on these, we will carry the 3-dimensional landslide stability analyses by ADCALC3D. By the series of study, the overall perspective will be realized.

1.4.5 Total Management Flow of Landslide Disaster Risks along the Main Roads in Tropical Mountain Ranges - Based on Research Accomplishments in Central Vietnam (Transactions Japanese Geomorphological Union, Vol. 38-4)

Report No.1

The report considers that total management flow should be set at the fact-finding and mapping stage, the risk evaluation stage, the categorizing stage, and at the management strategy set up stage. To assist investors (departments in charge of disaster prevention) and the engineer easy makes an accurate and effective decision for selecting the measures to responding to landslide disaster occur along the artery such as national road, it is necessary to build a comprehensive management system of landslide disaster risks. Especially in Vietnam, where the latest technical knowledge is not always reflected in the event of a landslide disaster outbreak in response procedures of departments in charge of disaster prevention. This study coordinates various processes from the evaluation of landslide disaster risks of and along roads through simulation of landslide occurrence to the proposal of a concept of countermeasures and monitoring into one workflow, to indicate a procedure to be conducted during each phase, and finally to propose a management system. For those purposes, the AHP hazard prediction method of reactivation risks of landslide topography for management classification is applied. The Japanese inspection sheet for landslide AHP score calculation is modified into more user-friendly representations for on-site use. In addition, the landslide scale, spatial relation with a road and the gradient of the slopes is examined comprehensively to calibrate the landslide risk score. Based on the final landslide risk score, disaster vulnerability is set in descending order from level 1 to level 4, which corresponding to four levels of strategies of road maintenance: 4) countermeasures immediately; 3) tracking tools; 2) patrol incentives, and 1) regular patrols. This management system might be applied to all of Southeast Asia as a humid tropical zone.

1.5 Strategy of Report Establishment

1.5.1 Research Objectives and Subjects

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. Although the Vietnam government has made from the overall to detail strategies to deal with natural disasters, it is able to be recognized that the responding in the face to this dangerous phenomenon seems to be still quite passive.

In recent years, more and more authors and agencies are interested in geology, landslide disasters to prevent and mitigate landslide disasters.

The new strategy for landslide hazard vulnerability mitigation in humid tropical region was proposed by Tien et al. (2014), which proposed the landslide classification by pattern recognition using fuzzy inference method, landslide susceptibility mapping by the AHP approach applied and mentioned to some guidelines for landslide hazard vulnerability mitigation in humid tropical.

In addition, the method of landslide mapping of aerial photograph interpretation and risk evaluation and approach for a humid tropical region are also mentioned (Luong et al., 2015). This is the method considered supposed to be suitable for large-scale landslides (Luong et al., 2016), while aerial photo data and taking new aerial photographs in Vietnam was not necessarily easy (Dung et al., 2016). Newly taken aerial photographs require huge expenses that are expected to challenge any real research budget. In addition, aerial photographs of the mountain region taken in the past were on a scale of about 1:33,000, clarifying that they were unsuitable for the recognition of micro landforms from them (Dung et al., 2016).

However, in reality, in Vietnam, up to 60% number of landslides is small and medium scale and mainly concentrated along traffic routes (Dung et al., 2016). Economic losses and disruption of local livelihoods are mainly caused by small and medium scale of landslides (Dung et al., 2016). Meanwhile, the response to natural disasters in Vietnam is still passive (Dung et al., 2016), the main reason is the difficulty in assessing and classifying to choice reasonable solutions.

Solving these problems, first of all, it is necessary to develop methods of survey, risk assessment, and classification suitable to the characteristics of landslide in Vietnam. The next step must build the method of determining the real slip surface, method of determining the mechanical properties of the rock on the slip surface to understand the mechanism of sliding. Finally, used the collected data to simulate the phenomenon, assess the safety factor and select the appropriate response solution.

Hence, the research objective is establishing a theoretical basis method to help engineers and managers to easily decisions making for landslides countermeasures in Vietnam and also in humid tropical regions.

The study subjects including a typical landslide on NH6 located at 95 km far from the starting point of NH6 in Hanoi, along HCMR corridors in the Central of Vietnam, special is sectioned from the Dakrong bridge (intersection with NH9, connecting Dong Ha - Quang Tri to Lao Bao border gate with Laos) to Kham Duc (Kon Tum), about 350km length and about 70km long of NH7 (section from Muong Xen to Son Ha).

1.5.2 Research Methodology

The research methodology is applied as under flowchart in Fig1.12, including four basic stages as (1) identify for landslide, (2) assessment for recognition the actual landslide and the slip mechanism, (3) evaluation for stabilizing the target landslide and (4) decision making for landslides countermeasures. Below is the detailed description of these stages.

(1) For identify a landslide, there are three methods to identify a landslide as using historical record data, field investigation, and aerial photo interpreter.

Currently, the number, location and landslide scale have occurred in some areas and along some routes have been statistical, however, the accuracy and reliability still need to be verified by actual field survey. Field investigation methods for a landslide are feasible and easy to implement for small scale, but it is difficult for a large scale, then aerial photo interpreter method should be applied. The identification of large-scale landslide topographic area ("landslide topographic area") is carried by the stereo pair aerial photo interpretation (Miyagi, 2014). In addition, landslide topography mapping using W3D data from ALOS W3Ddata can be applied (Dung et al., 2016).

(2) Assessment for recognization the actual landslide and the slip mechanism by field investigation to clarify the micro feature of landslide. Landslide type, landslide scale, spatial relation to a road, and the micro-topography features as head, crown cracks, scarps, minor scarps, main body, the surface of rupture, crown, transverse ridges, foot, radial cracks, etc., must be clarified. Field survey techniques that have been used by the authors and colleagues, followed by the Analytic Hierarchy Process (AHP) hazard prediction method of reactivation risks of landslide topography (Miyagi et al., 2004, Hamasaki et al., 2014, Tien et al., 2016, Luong et al., 2016). The Inspection sheet for landslide AHP score calculation is revised into more user-friendly representations for on-site use.

Clarify the mechanism of the landslide by field investigation base analysis of landslide activities. Deduce the slip surface by field investigation and field experiments.

(3) Evaluation for stabilizing the target landslide.

Based on collecting data of field investigation and the results of the experiments, the simulation of the sliding process will be carried out. And analysis the safety coefficient of the landslide body in assuming conditions of groundwater level change. The groundwater level assumes a change in the rule and the cycle of precipitation at some specific landslide sites on NH6, NH7, and HCMR. The simulation, computation is carried using analysis, simulation software.

(4) Decisions making for landslides countermeasures:

By coordinating the results of three stages above and adding three important criteria as the landslide scale, spatial relation with a road and the gradient of the slopes is examined comprehensively to calibrate the landslide risk score. Based on the final landslide risk score, disaster vulnerability is set in descending order from level 1 to level 4, which corresponding to four levels of strategies of road maintenance: 4) countermeasures immediately; 3) tracking tools; 2) patrol incentives, and 1) regular patrols.

A concept of countermeasures and monitoring into one workflow, to indicate a procedure to be conducted during each phase, and finally, a management system is proposed. This management system might be applied to Vietnam and also to all of Southeast Asia as a humid tropical zone.

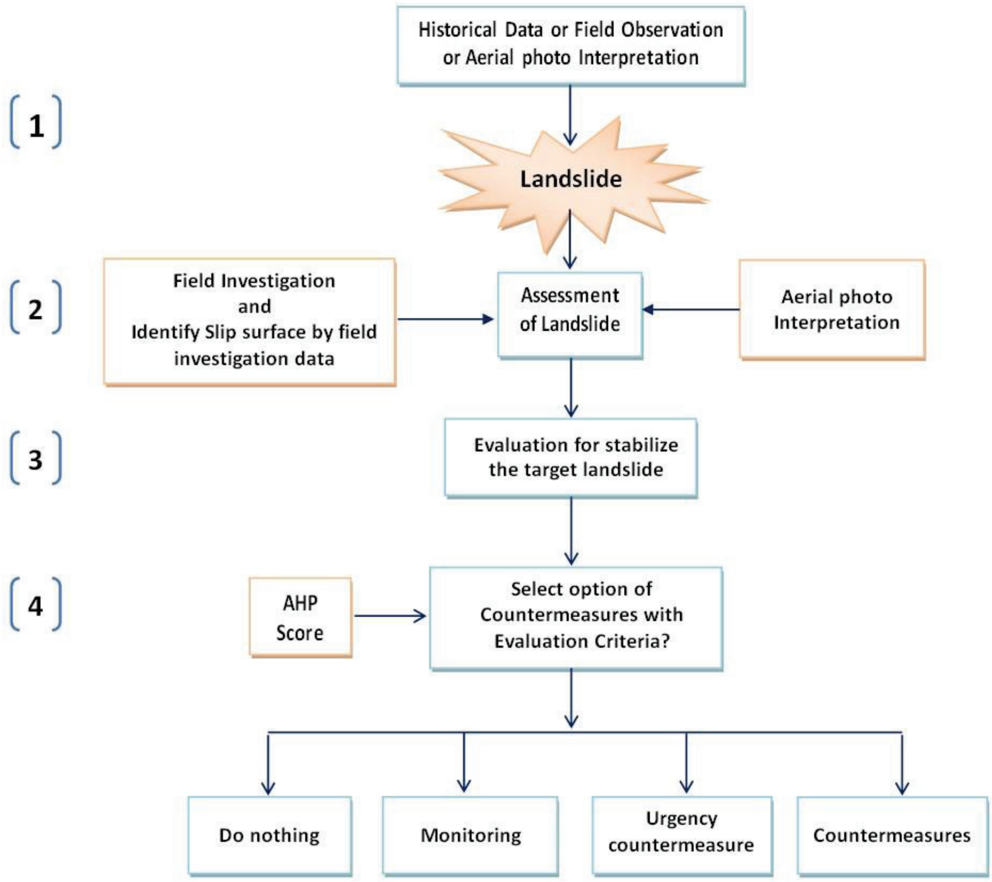

Fig. 1. 12 Flowchart for Total Management of Landslide Disaster Risks along Main Roads in Tropical Mountain Ranges

1.5.3 Main contents of research

Title of research:

Total Management of Landslide Disaster Risks along Main Roads in Tropical Mountain Ranges

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CHAPTER 2. LANDSLIDES DISASTER ALONG TRANSPORT ARTERIES IN VIETNAM

2.1 Landslide disaster along Transport Arteries in Vietnam

The railways and road network in Vietnam mainly run from the North to the South. Vietnam has more than 90 national routes with 20,654 km long and it accounts for 7.5% of the total length of the road network (Directorate for Road of Vietnam (DRVN) - Ministry of Transport, 2015). In which, three quarters of a length of highway going through mountainous regions and about 30% of those passes through areas with complex geological structures, influenced by the tectonic destruction zones. Similarly, a percentage of 30% in length of its other routes are located on the plains where the geology is fluviatile deposits, marine sediment or soft ground. Besides, Vietnam is geographically located in the highest rainfall area in the world and affected by monsoon climate. Typhoons and floods often occur usually from July to November with an annual density of five to seven times per year, equaling 99% of the frequency of annual floods. As a result, landslides frequently occur in transport arteries during rainy season, especially the new traffic routes have been being built and reconstructed. The total annual volume of landslides reaches to several hundred thousands of cubic meter. The landslides not only cause traffic congestion on roads and serious economic loss by destroying infrastructures, but also threaten the stability of local communities in mountainous regions. Annual funds for flood prevention, traffic guarantee and landslide treatment on road network often account for hundreds of millions US dollars.

The landslide phenomenon on the National Highway (NH) occurs primarily in the Northwestern mountains and along the Truong Son range in the Central region of Vietnam. According to preliminary statistics of the Institute of Science and Technology of Transport (ITST), the landslide phenomenon mainly occurs on national highways such as NH1A, NH2, NH3, NH4D, NH6, NH7, NH8, NH12A, NH14, NH24, NH25, NH26, NH27, NH32, NH37, NH49A and NH279, etc. Especially is on HCMR at some sections going through the Central area. ITST reviewed and found that the small-scale of landslides accounts for over 60%, the rest is the medium to large and even very large scale landslides, causing traffic jam during the rainy seasons.

2.1.1 Landslides along National Highway 1A

National Highway 1A is an important road passing through 31 provinces and cities of Vietnam. It starts at Km0+00 at Huu Nghi border gate, between border Vietnam and China in North and ends at Km 2301+340 in the Ca Mau province in the South. According to MOT, there are hundreds of landslides along this road and mainly occur in the rainy seasons nearby the rivers or through the passes such as Ngang pass, Hai Van pass, Deo Ca pass Phu Gia pass and Phuoc Tuong pass, etc. in the Central of Vietnam.

The Hai Van pass station is a particularly important position on the North-South railway line in the Central region (Fig 2.2). Located on the lower position of the peck of Bach Ma range, overlooking the beach that has a special geological structure with unconsolidated

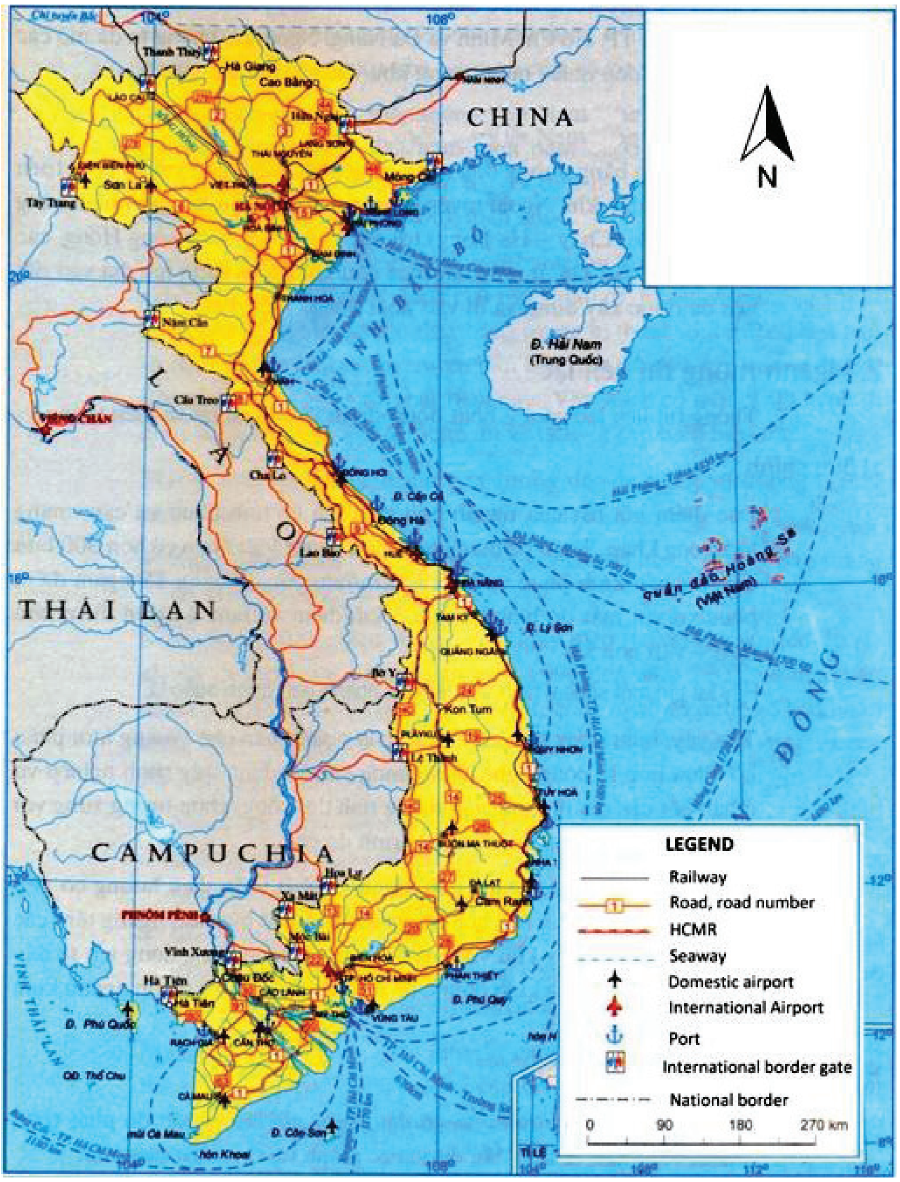


Fig.2. 1 Transportation network of Vietnam

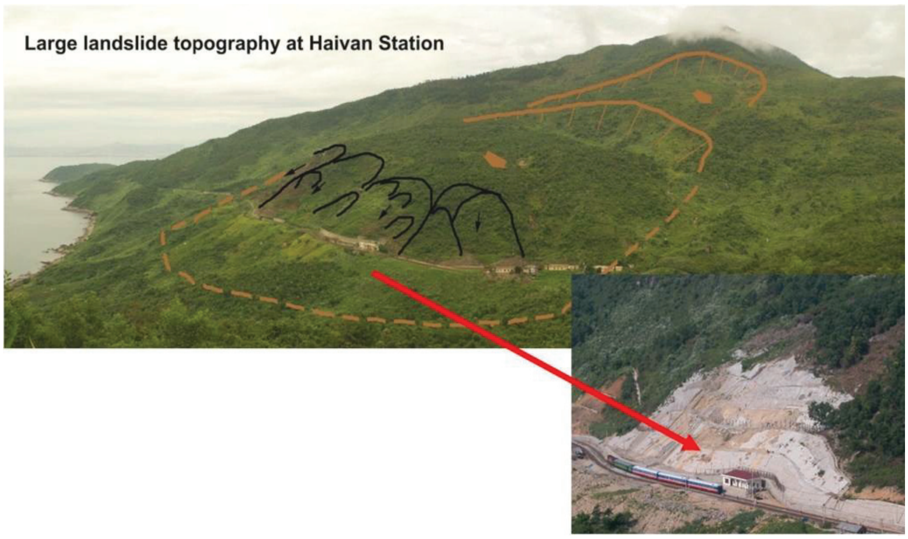


Fig.2. 2 Deep landslides on Hai Van Pass station

soil mixed with granite rocks, this area received a very large rainfall yearly (over 3000 mm/year). Over 30 trains are passing through this station each day. Landslide phenomenon is the greatest threat to the lives of passengers using trains when passing through this area in the rainy season. This landslide was strengthened by concrete frame and retaining wall. After less than 4 months of operation and although not faced with the rainy season yet, but this countermeasure was seriously damaged. Construction materials, concrete patches, steel bars for landslide strengthening had broken and rushed. Many "orphaned" rocks of having loose leg rolled down and located in the middle of the slopes wondrously. Railway line and station located right at the foot of this mountain was a serious threat.

The causes of this serious landslide concerning complex geological and climatic conditions of this region, it also seems to be related to unsuitable strengthening solution while that was not yet fully assessed the classification and the scale of landslide. The landslide phenomenon here is the most of anxiety of Vietnam railway that not only occurs during the rainy season but also have a direct threat to the safety of trains and lives of passengers whenever the train runs through this area.

The area of Deo Ca Pass, there was three landslides generated after a prolonged rainfall in 2005 and most seriously, a down movement of 30,000 m^3 soils buried 150 m long on the road (DRVN). The area of Co Ma pass in Phu Yen province, there were 17 landslides along the 17 km long with the medium and the large scale.

2.1.2 Landslides along National Highway 6

National Highway 6 is the road linking the Hanoi capital with the northwestern provinces of Vietnam. The total length of the road is 504 km and passes through 4 provinces and cities (Hanoi, Hoa Binh, Son La and Dien Bien). There are 10 long and steep Pass with the length from 4 to 33 km on this road. These Passes are evaluated and assigned as very highly sensitive with landslides in the countermeasure plan. The sensitivity was assessed on the basis of comparison of some factors affecting the stability of the cutting slope such as slope angle, digging height of slope, the appearance of cracks, natural geological formations and the history of tectonic activities. These activities were considered as cause creates new faults that disrupted the geologic structure and changed the characters of metamorphic and crumpled fractured sedimentary rock, improved water infiltration, reduced shear capacity of rocks in the region.

Fig.2. 3 Location map of NH6

Fig.2. 4 Landslide warning board at Km71+480 and a landslide at Km138+750 along NH6

There are hundred locations of high potential of landslide and more than 50 locations most frequently occurring in the rainy seasons have been recorded on this route.

Section passing through Hoa Binh province is 119 km (from Km39 to Km158), there are about 30 locations of high risk of landslide. At these 30 locations, there are 17 locations frequently occur landslide. Which are concentrated in sloping areas, passing through communes as Tan Son, Dong Bang, Thung Khe, Thung Nhuoi, Doc Ma, Doc Cun. Particularly due to the effects of the typhoon that occurred in October 2007, during the period from Monday to Friday, a heavy rainfall with great intensity of 400-500mm has caused many sections of the road to be deeply inundated and serious landslides occurred. A massive 250,000 m^3 of rock mass from the slope collapsed on the road, causing traffic jam in 7 days and destroyed 17,000 m^2 asphalt pavement (DRVN). Most serious cases are the rapid slope failures of 150,000 m^3 of debris from the artificial slope which occurred on 2012 Jan 16 on Km138+750, located in Dong Bang commune, Mai Chau district, Hoa Binh province, killed two people and causing traffic congestion for several days. Another most recent rapid slope failure of more than 20,000m^3 of soil and rock on 2013 February 22 (in dry season) on Km138+800, caused traffic jams for hours. Fortunately, this landslide did not damage the lives and property of the people.

The assessment of moving slopes is a complex issue depending on many factors, which need analysis based on a combination of scientific analysis and expert opinion. The identification and assessment of the risk level in a number of cases can be recognized through the signal of movement, such as partly slides moving or cracks appearing on the slopes through site survey or by analyzing of some particularly crucial param such as the geological structure, the slope characteristics and the height of slope.

However, it did not provide an accurate and qualitatively comparative evaluation. Some slopes belong to high risk and very high risk group of landslide even there are no signs of movement that cannot be found. In case of landslides along NH6 in Hoa Binh province, the landslides occurred as partly rapid slope failures.

2.1.3 Landslides along National Highway 7

National Highway 7 is 225 km long, situated entirely in Nghe An province. It starts from Dien Chau town of Dien Chau district (intersection with NH1A) and ends at Nam Can border gate at Laos border. This route runs through the districts of Yen Thanh, Do Luong, Anh Son, Con Cuong, Tuong Duong, Ky Son. Most townships of the aforementioned districts (Dien Chau, Do Luong, Anh Son, Con Cuong, Hoa Binh, Muong Xen) are located on NH7. Rarely landslide occurred between Do Luong - Dien Chau segment. Segment of Do Luong - Nam Can is 192 km long, running along Ca River and go through the 20 km long of Bacteremia pass, longitudinal gradient up to 10-12% and many segments have the height of slope to hundreds of meter and landslide often occurred during the rainy season.

NH7 lies along the major fault zones of Ca River, from the Northwest to the Southeast. The rock has undergone complex tectonic activities and formed the anticlinal mountains of Northern-Central with Phu Hoat complex folded anticlinal, Ca River complex syncline and Sam Nua complex syncline and Truong Son complex folded anticlinal. The rock layers were raised, subsided, curved, crumpled, crushed, separated by faulty systems, various cracks formed and the weathering processes making rock system becomes weak.

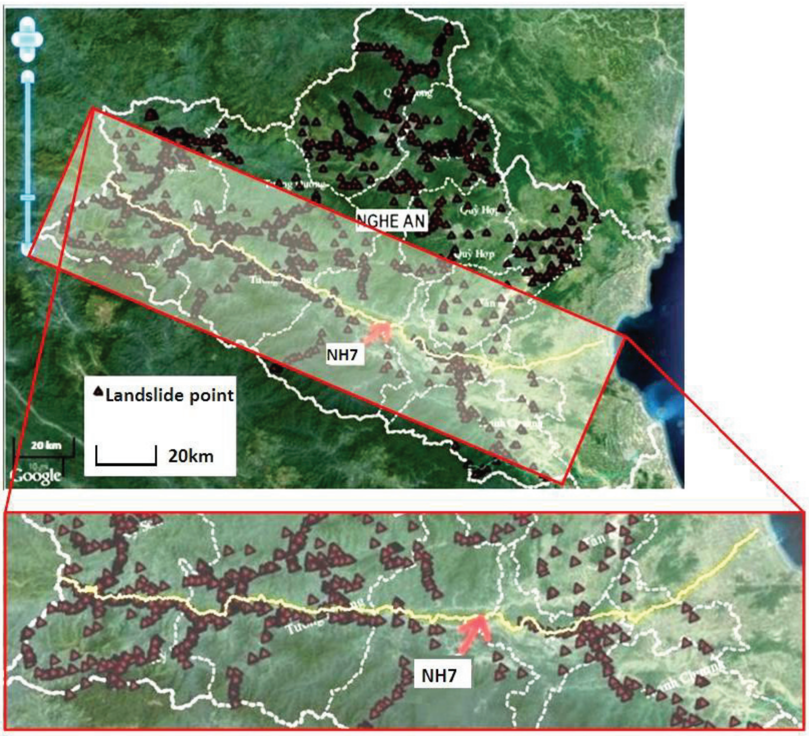


Fig.2. 5 Landslides distribution map at Nghe An and along NH7 (VIGMR, 2013)

The stability of slopes depends on bedding plane of rock and mechanical properties of this weaknesses surface. The cases that the layered surface of shale have faults and major crack system plugged into the space of the slope is the cases that are high of potential landslides. Together with endogenous processes, phenomena and geological processes exogenous motivation work as weathering, karst, moving rocks on the slope, surface runoff and gully erosion, sand erosion and groundwater flows, erosion, etc., have a significant impact on the failures in this area.

In the mountainous area of Nghe An, more than 1347 locations of landslides were interpreted from aerial photos and terrain analysis on DEM, and more than 1298 locations were identified from field investigations (VIGMR, 2013). Among them, only 192 km long of NH7 of a segment from Nam Can to Do Luong have more than 150 locations. These landslides mainly concentrated in the areas such as Anh Son, Tuong Duong and Ky Son. They had a serious impact on traffic and the lives of people in these mountainous districts (Fig 2.5).

2.1.4 Landslides along HCMR

HCMR is a lifeline system and parallel with NH1A, which runs from the North to the South of Vietnam with the total length of 3,167 km. It has been being built and will be completed in 2020. Because of passing through mountainous topography, complex geology and adverse climate, landslides densely distribute along the road with more than 1600 locations (statistical data of ITST).

In October 2003, induced by prolonged and heavy rainfall with a cumulative precipitation of 428,1 mm. A landslides at Km516+713 to Km516+891, was 100,000 m^3 in volume with the length of 172m along the foot of slope and a depth between 2 to 5m, caused damages to retaining wall partially and ditch system on the top of slope completely.

During the 2007 rainy season, a series of 187 landslides happened along route from Dakrong-Ngoc Hoi with a medium and large scale and concentrated on sections of A Dot-A Tep, A Tep-Prao, Prao-Thanh My, and Kham Duc-Lo Xo pass. Similarly, due to storm No.5 in 2007, landslides occurred on the Da Deo pass and other landslides after a heavy rainfall. Consequently, a down movement of several thousand cubic m of soils caused traffic congestion in a week and affected storm prevention works. More than 250,000 residents were rescued in flood areas as well.

According to Ministry of Natural Resources and Environment (2008), the detailed survey in 13 sections along HCMR showed that there were eight intensive landslide prone locations in rainy season including:

1) Da Deo – Khe Gat section located in Bo Trach district, Quang Binh province with the length of 9 km has 4 landslides at the scale from 1000 m^3 to 100,000 m^3 in volume.

2) The Northern of U Bo section in Bo Trach, Quang Binh province (29km long) has a large scale, 30 small and medium scale landslide. 3) The length of 10km of Khu Dang Pass in Quang Binh province has 3 large-scale landslides, up to 350,000 m^3 in volume. 4) The length of 31km long of Cong Troi Pass in Quang Binh province has 15 landslides with medium and large-scale. 5) The length of 22km on Sa Mu Pass in Quang Tri has 13 small and medium scale landslides and 3 large-scale landslides from 40,000 m^3 to 80,000 m^3. 6) On the Hai Ham Pass section (25km in length-Thua Thien Hue), there were 4 medium scale and 24 large-scale landslides. 7) The length of 25km on Song Bung Pass (Quang Nam) has 4 large-scale landslides with a volume up to 200,000 m^3. 8) On Lo xo Pass in Kom Tum province (length of 20km) has 7 large-scale landslides.

According to the Landslide susceptibility map along HCMR scale of 1: 500,000 (Tien et al, 2011), in the section from Nghe An to Kon Tum there are 26.46% of the area of higher risk and very high risk of landslides and medium risk is 43.77% and the low is 29.77 % total area (Fig 2.6).

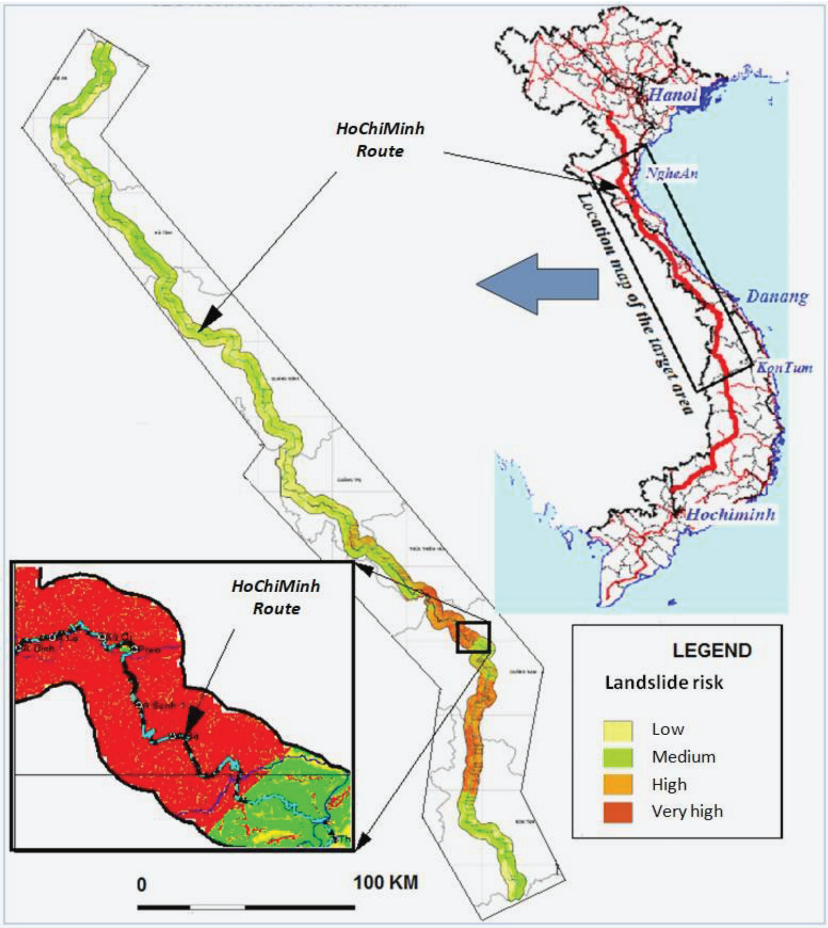


Fig.2. 6 The landslide susceptibility map along HCMR section from Nghe An to Kon Tum

2.1.5 Landslides along National Highway 4D

National highway 4D is a strategically important borderline linking the Eastern and Western districts of Hoang Lien Son range, about 160km long, passing through Lao Cai and Lai Chau provinces. This route mostly has cut slopes with 20-50 m high, excavation in the natural slope angle from 60 to 80 degrees. The route direction of the Northeast - Southwest is almost quadrate to the main fault system in the area, cutting through compression zones, broken by geological activities. Along the route, there are many sections of loose materials, typically the weathering layers of the contact zones between the intrusive blocks of Posen and ChaPa formations. Quaterdary formation and sediments are compressed and crushed zones in the intrusive blocks of Posen. These materials will be dangerous sliding blocks for traffic on the road if there are sloping terrain and saturated rainwater. Status of landslides at the section from Km64+800 to Km85+35 and the area of Mong Sen Bridge (Km119) is particularly serious. According to research and survey results over the period from 2001 to 2003, from Sapa town to Mong Sen Bridge there were 81 identified landslides (Ngoi C.V and Ha N.T.T, 2008). Landslides are distributed on the slopes with a slope angle of 22 to 45 degrees, which is concentrated in shear zones with crumbling rocks and weathered shells with clay. Typically, at Km119 in June 24th, 2004, a mass of landslides with approximately 2.000m^3 from the 40m high slope suddenly collapsed into the construction site, killed two workers, injured one person and made two cars down to deep.

On September 20th, 2014, on Km74 + 800 belonging to Hoang Lien Son Pass, Son Binh Commune, Tam Duong District (Lai Chau Province), a serious landslide occurred and caused about 10,000m^3 of rock from the mountain to enter the roadway. The traffic on the NH4D is paralyzed, completely separated Lao Cai from Lai Chau Province (Fig 2.7).

Fig.2. 7 Landslide on National Highway 4D (September 20th, 2014)

2.1.6 Landslides along other Routes

According to survey results of ITST in 2012, a segment from Bac Can City to Ta Lung border gate on the National Highway 3 (NH3), there were about 50 in large and small scale landslides, focusing on Giang Pass (6 locations), Gio Pass (13 locations), from the North of Gio Pass to Cao Bang City (17 locations), and crossing Cao Bang city (7 locations).

On the National highway 279 (NH279), only from Km33+450 to Km154+080 have about 50 landslides. On July 6th, 1977, at Km33+450, near the Huoi Quang hydroelectric power plant (Muong La district, Son La province), caused by heavy rains was made nearly 800m^3 of rock that filled the entire 70m of road and damaged the plumping of many households (Fig 2.8).

In the middle of July, 1995, on the National highway 37 (NH37), in the area of Km125 - Km126, a landslide mass from 60 to 70m high slipped down, destroyed 24 durable houses in the foothills, killed one person. The landslide created a scarp high 8m and raised the asphalt surface to a height of 1.50m like a dam.

Fig.2. 8 Landslide caused serious traffic congestion on National Route 279

2.2 Causes of Landslides

In fact, the occurrence of landslides phenomenon is as the result caused by synthetic impacts of a series of factors, including geology, topography and geomorphology, meteorology, hydrology, vegetation and human activities. In which, role of each element is also different at each time to induce sliding (Fig 2.9).

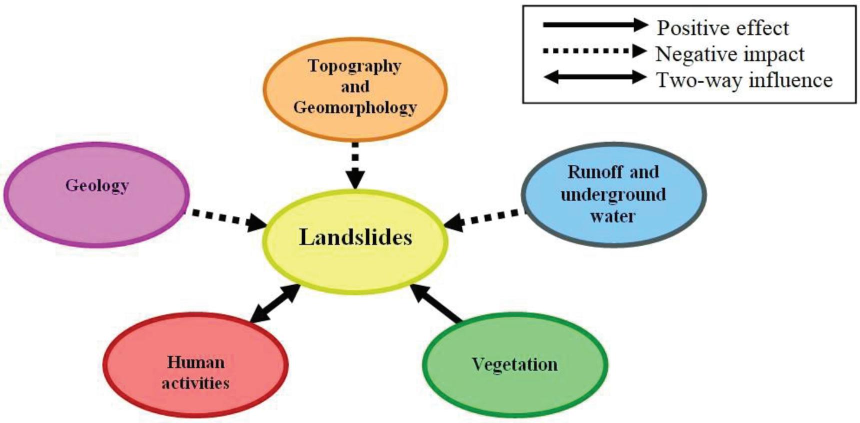


Fig.2. 9 Main factors impact to the appearance of landslides

2.2.1 Climatic conditions

When assessing the landslide risk and the construction of a countermeasure, should be paid special attention to weather conditions, because of the fact that there is a very close relationship between precipitation and landslide distribution. Landslide cycle is usually coincident with rain cycle. During prolonged rains, rainwater easily absorbs into deep soil layers, which makes saturated soils in slopes. Meanwhile, a heavy rain but short, most of water will runoff on the surface, only a small part of it penetrates into the soil. In the region of hot and dry climates, the evaporation of rock and soil on steep slopes contributing increases the stability of the slope. The influence of the climate conditions of the pore water pressure under the ground surface is shown in Fig 2.10.

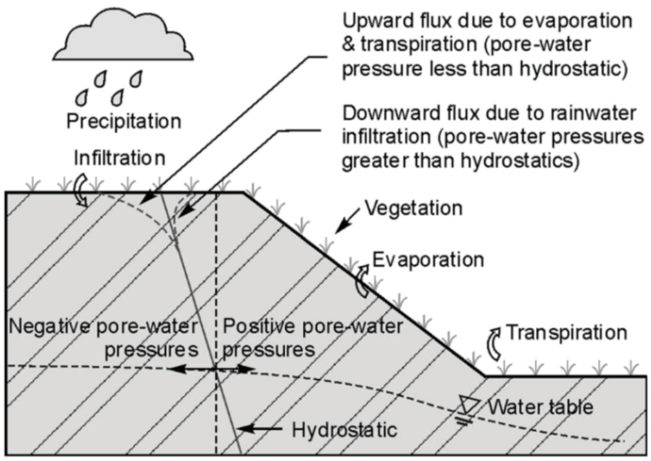


Fig.2. 10 Schematic representation of effect of climatic conditions on pore-water pressure profile near ground surface of slope (Rahardjo H. et al., 2007)

2.2.1.1 General climatic characteristics

Vietnam is located in the tropics, but due to its narrow horizontal (East-West) territory and its longitude (North-South), the climate of mainland is divided into three distinct climatic zones (Fig 2.11), which are (1) The climate in the north is subtropical, 2) The Truong Son climate is characterized by a tropical monsoon climate, (3) the Southern climates are characterized by tropical Xavan. At the same time, as it lies on the South-Eastern margin of the continental part of Asia, which borders the South China Sea (part of the Pacific Ocean), it is directly affected by the monsoon climate. In the winter, there is blowing air from the continent and from the Western Pacific with high pressure of carrying dry and cold air. Summer includes tropical west winds, equatorial air and air flow from the South Pacific carrying hot, humid air from the ocean (Fig 2.12).

Meteorological elements are strongly distributed in space. Winter temperatures tend to increase from North to South, from West to East. Rainfall distribution is uneven.

Fig.2. 11 Vietnam map of climate classification (based on Köppen climate classification)

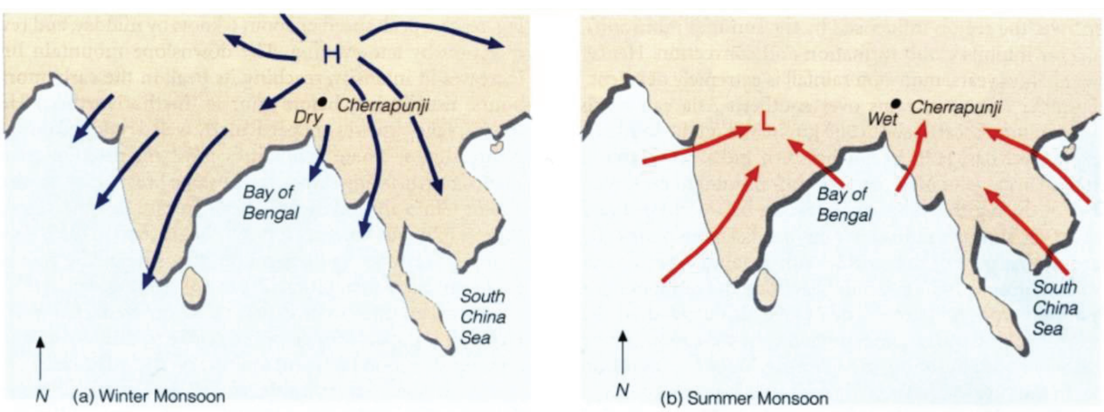


Fig.2. 12 Winter and Summer Monsoon in Southeast Asia

(1) Northern climatic zone covers the northern part of the Hoanh Son Range, from 18 degrees North. This region has a subtropical humid climate with four distinct seasons: spring, summer, autumn and winter. However, this climate is characterized instabily by the beginning and the end of seasons and temperature.

The North East zone (Fig 2.22) includes the Northern Plains, the Northern Midlands and Mountains (Eastern part of Hoang Lien Son Range). This region is characterized by quite flat terrain (Northern plains) and low.

In the North, there are high mountains ranging from 1,000 m to 3,000 m in the Northeast - Southwest, North - South and North West North - South East South directions, converging towards the Tam Dao mountain range. It is the bow of Dong Trieu, Bac Son, Ngan Son, and Song Gam, and ends with the Hoang Lien Son Range on the border with the Northwest. It does not prevent the formation of North, Northeast winds and it often blows in the winter.

The East is bordered by the Northern Gulf. The Western side is blocked by the Hoang Lien Son Range, the tallest in Vietnam, so it is influenced by the oceanic climate and is directly affected by the tropical cyclone. In the summer it is less affected by foehn wind (known as the Laos wind).

The Northwest's terrain (Fig 2.23) has many mountains and high mountains running in the direction of North West - South East. The Hoang Lien Son Range is 180 km long, 30km wide, with some high peaks of between 2800 and 3000m. The Song Ma Range is 500 km long, with peaks over 1800 m. Between these two mountain ranges is the low mountainous area of the Da river basin. In addition to the Da River is a large river, in the North West has small rivers and streams including the upper Ma River. In the Da river basin, there is a limestone plateau running from PhongTho - Lai Chau to ThanhHoa, and can be subdivided into Ta Phinh, MocChau and Na San. There are also basins such as Dien Bien, Nghia Lo and MuongThanh.

Although the general climate in the North West does not make a big difference among regions, its expression varies horizontally and vertically. The Hoang Lien Son mountain range runs a block in the direction of the Northwest - South East is serving as a wall to prevent the winter winds (Northeast and Southwest) to enter Northwest Territories. In the Northeast, there is a system of enlarged fan-shaped arcs that allow cold waves to follow as far as the Red River delta and further south. Therefore, unless the effects of altitude, the Northwest is generally warmer than the Northeast, the difference may be two to three degrees. In the mountainous areas, the slope direction plays a vital role in the heat - humidity regime, and the wind catcher (eastern slope) receives heavy rainfall while on the western slope, there is foehn wind (Laos wind) blowing down the valleys, in particular in the Northwest.

In general, in terms of midland and mountainous areas, climate research is very important because climate variations occur in small areas. Climate events in mountainous areas are extreme, especially in the case of degraded forest cover and weathered soil cover. Concentrated heavy rains cause flooding, flash floods accompanied by landslides.

(2) The climate of the Truong Son zone (Truong Son is the longest mountain range in

Vietnam, covering over 1100 km running along the Western border of the terrain, starting from the upper Ca river on Laos border with Nghe An province to the Southern point of the Central), includes the Eastern part of the Truong Son Range, extending from the South of Hoanh Son (18 degrees North) to Mui Dinh - Phan Thiet (11 degrees North), is in monsoon zones. This domain can be divided into two regions:

+ The North Central is the Northern part of Hai Van Pass, there is sometimes cold and hot, dry periods caused by Southwestern winds. In winter, due to the shape running along the East coast in the direction of Northwest - Southeast, the dominant monsoon winds, this season is the Northeast monsoon. The mountain range of the Phong Nha - Ke Bang mountains are relatively high in the West and Bach Ma Range in the South, which are at the end of the Northeast monsoon, so the area is still affected by cold weather and often accompanied with heavy rains (especially in Thua Thien Hue) due to the monsoon winds blow in the northeast with the water vapor from the sea, slightly different from the dry weather of the North in winter.

The Northeast monsoon blooming here is often weakened and blocked by the Bach Ma Range, thus having a few effects on the Southern regions. In the summer, when the strong Southwest monsoon blows from the Gulf of Thailand across the vast continent to the Truong Son mountain range, it pours rain on the west side of the Truong Son, but continues to cross the mountains to blow into this area. At this time, due to the absence of water vapor, the Southwest monsoon causes hot-dry weather (sometimes greater than 40 degrees, humidity is only 50 – 60%), called foehn wind.

+ The Southern Central Coast region is the Southern Central Coastal plain of Southern Hai Van Pass similar to the northern Hai Van Pass. However, the temperature is higher and occasionally there are cold winters which do not last long. The effect of hot-dry west wind is not as great as that in the North Central. The rainy season starts from August to November (Autumn - Winter). The reason is that in the summer, this area is located in the southwest wind slope (or parallel to the wind direction in the South Central), it is less rainy, but in the Autumn and Winter, the impact of tropical convergence band along with storm season causes heavy rains.

An important feature of the Truong Son's climate is that the rainy season and the dry season do not coincide with the rainy and dry seasons of the other two climatic zones. In the summer, when the country has the largest rainfall, the climate is at its driest. Table 2.1 shows the annual average value of the climatic factors of the Truong Son climate region.

(3) The Southern climate, including the territory of the Central Highlands and the South, has Xavan tropical climate with two seasons: the dry and rainy season (April - May to October - November). This climate has not varied for years.

+ Tay Nguyen with Xavan tropical climate, and a quite low temperature background. The temperature drops significantly in midwinter (December-January), and then increases rapidly, hit a peak in the transition months from Winter to Summer (April and May). This area is divided into two seasons: the rainy season from May to the end of October (Summer - Autumn) due to the Summer monsoon from the sea in the rain and dry season from November to April, in which March and April are the hottest and driest months.

The average annual temperature is 24 - 28 degree and the hottest month temperature is 24 - 28 degree. The highest absolute temperature is 37 - 40 degree. The average temperature of the coldest month is 19 - 21 degree; the absolute lowest temperature is 3 - 9 degree.

The Central Highlands has an average annual rainfall of about 1,400-2,000mm. The rainy season is from May to October, mostly in July, August and September. Average relative humidity is about 78 - 84%, the average annual evaporation is about 900 - 1600mm. Droughts usually occur from the second half of Winter through Spring to early Summer.

+ The Southern climate is characterized with high sunshine, high temperature throughout the year, the rainy season basically coincides with Summer, the dry season mainly in the middle and late Winter, early Summer. The contrast of the rainy season is markedly better than the heat season.

The annual average temperature is about 26.5 - 27.5 degree and the hottest month is 28-29 degree. The highest absolute temperature is 38-40 degree. The average temperature of the coldest month is 24-26 degree and the lowest is 14-18 degree.

Tab.2. 1 Annual average values of climatic factors in the Truong Son climate region (General Statistics Office of Vietnam)

No	Station name	Hours of Sunshine (hours)	Air temperature (*C)	Relative humidity (%)	Total cloud cover (1/10)	Wind speed (m/s)	Potential evaporation (mm)	Annual rainfall (mm)
1	Tuyen Hoa	1,575	24.1	85	7.9	2.0	1,197	2,400
2	Ba Don	1,842	24.7	84	8.0	1.8	1,291	2,077
3	Dong Hoi	1,869	24.7	82	8.0	2.4	1,364	2,237
4	Dong Ha	1,881	25.8	82	7.9	2.5	1,433	2,294
5	Khe Sanh	1,884	22.6	88	7.9	2.6	1,140	2,006
6	Hue	1,945	25.2	83	7.6	1.6	1,101	2,478
7	A Luoi	1,746	21.6	87	8.2	1.7	1,065	3,222
8	Nam Dong	1,912	24.5	85	7.0	1.3	1,193	3,546
9	Da Nang	2,261	25.7	82	8.2	1.6	1,440	2,126
10	Tam Ky	2,255	25.6	83	6.8	1.8	1,382	2,602
11	Tra My	1,874	24.4	87	7.5	0.8	1,087	4,105
12	Quang Ngai	2,205	25.7	85	6.6	1.3	1,367	2,334
13	Ba To	1,996	25.3	85	6.3	1.3	1,127	3,408
14	Son Hoa	2,345	26.0	81	7.3	1.6	1,602	2,189
15	Quy Nhon	2,498	27.3	79	6.4	1.9	1,637	1,906
16	Hoai Nhon	2,421	26.1	82	6.2	1.7	1,464	2,007
17	Tuy Hoa	2,529	26.6	80	6.1	2.3	1,654	1,968

The annual rainfall is about 1,600-2,000mm. The rainy season is from May to October, mostly in August, September and October. The average relative humidity is about 78 - 84% and the annual evaporation is about 1100 - 1500mm. Droughts often occur in the second half of winter and spring.

2.2.1.2 Typhoons and Tropical depressions

Due to geographical location, Vietnam is influenced by many weather patterns such as tropical cyclones, tropical depression, cold air, tropical convergence, etc., individually or in combination. Typhoons and tropical depressions are derived from offshore landings, usually concentrate in the Central coastal provinces from Thanh Hoa to Quang Ngai or sometimes Northern provinces, and rarely occur in the Southern provinces. Almost storms occur between August and November, with an average frequency of 1.3 to 1.7 storms per month (Vietnam Hydro Meteorological Atlas, 2005), (Fig. 2.13). In the period from 1961 to 2010, there were 381 storms and tropical depressions affecting Vietnam, with an average of 7.62 attacks per year. There were at most 14 attacks per year (1989 and 1995) and at least 2 attacks per year (1969 and 1976) (Thang N.V, 2010).

2.2.1.3 Rainfall:

Bordered by Pacific Ocean and located in the highest rainfall area in the world, Vietnam is influenced by the monsoon climate with the average annual rainfall from as much as 3,000-4,500mm. Heavy rain in Vietnam is a result of some forms such as storms, tropical depressions, tropical convergence, cold air, broken lines, etc. Especially when there is a combination, they can cause prolonged rains in a wide range. According to statistics, there are average 25 heavy rains across the country every year. The period of heavy rains ranging from April to December begins earlier in the Northern regions and later in the Southern regions (Chinh N.D, 2004).

The characteristics of the terrain as the direction of the mountain ranges are Northwest - Southeast, the height of the mountain, the direction of the wind blowing season, etc., are very important factors, decisive characteristics of rainfall distribution in Vietnam. Heavy and especially large rainfall is mainly distributed in the mountainous areas in the North West and Central of Vietnam from Hue to Quang Ngai province (Fig. 2.14).

Northwestern region has the highest mountain range, Hoang Lien Son (Fansipan is 3140m high). It is located in the northwest - southeast to prevent Northeast monsoon, Southwest monsoon, which increases the amount of precipitation on both sides of the slopes adding rainfall to the area. The rainy season here is quite early and short, from April to October. The annual average rainfall (Xo) is unevenly distributed in the area, decreases with the elevation of the terrain and in the direction of Northwest - Southeast, varies from over 1,400mm to over 2,800mm. Heavy rain centers (Xo> 2,400mm) are found on both sides of the Hoang Lien Son Mountain Range, Tam Dao Range and Ba Vi Range, such as Sin Ho (Lai Chau, 2400-3200 mm), Sapa (Lao Cai, 2400-3600mm), Bac Quang (Ha Giang, 2400-5000mm), Mong Cai (Quang Ninh, 2400- 2800mm), Tam Dao (Vinh Phuc, 2400- 2800mm), etc (Vietnam Hydro Meteorological Atlas, 2004).

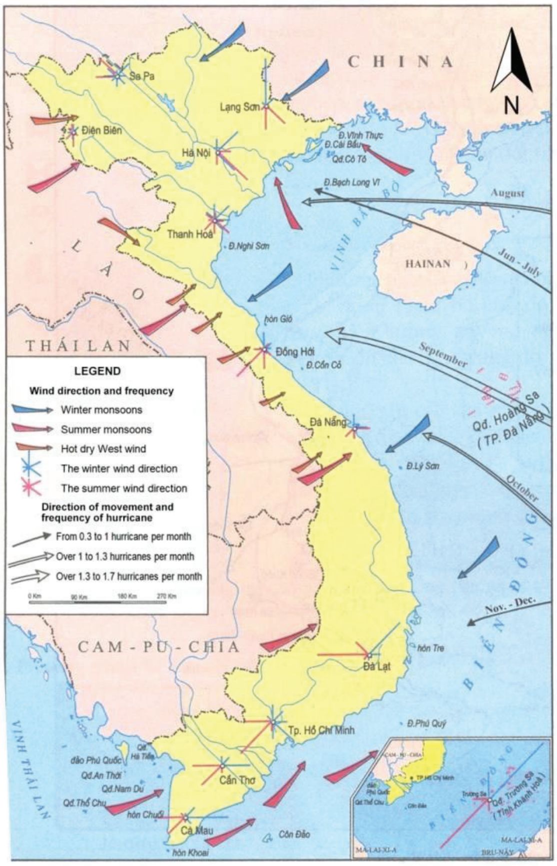


Fig.2. 13 Winds direction and typhoons map of Vietnam (VHM Atlas, 2005)

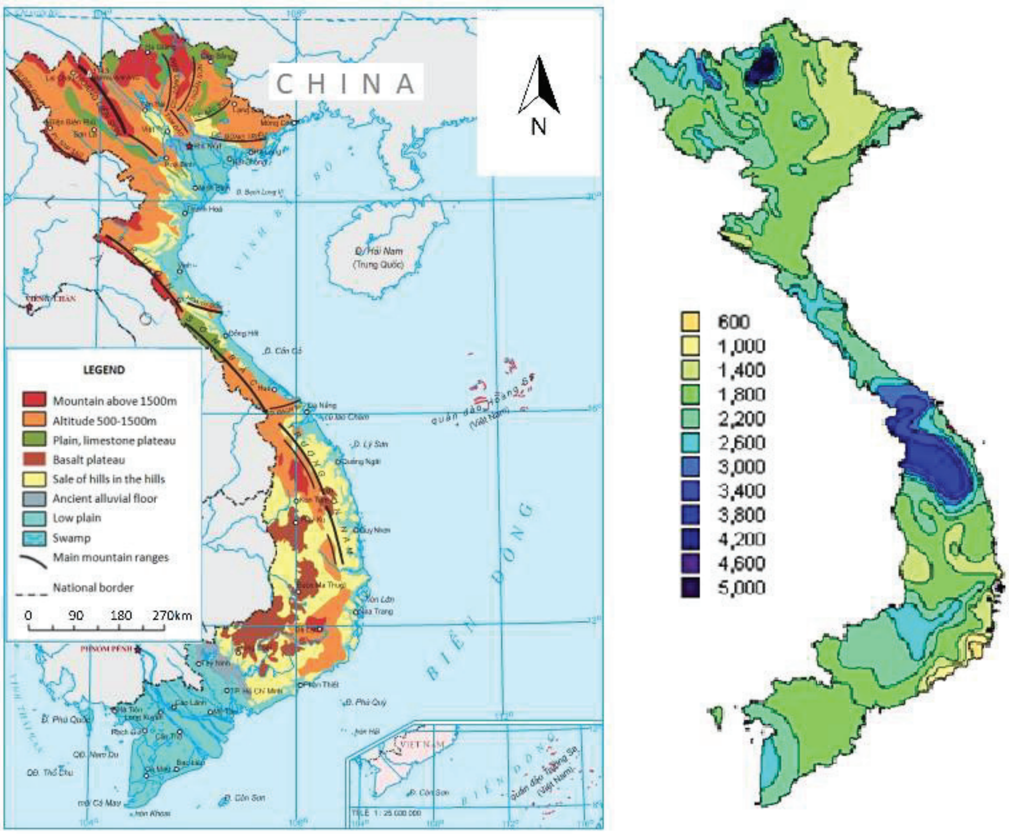


Fig.2. 14 Map of main mountain ranges and distribution of precipitation in Vietnam (mm)

In the Central Region, the Truong Son Range divides the central land strip into two distinct areas, Eastern Truong Son and Western Truong Son. In winter, Eastern Truong Son slopes have an unusually heavy rainfall, while the western side is dry and hot, while in summer the opposite is true, Western Truong Son has much more rain.

In the North of Bach Ma Range (northern part of Hai Van Pass), it is sometimes cold and has hot and dry periods due to the southwest wind. In winter, due to the shape running along the east coast in the direction of Northwest - Southeast, the northeast monsoon is the dominant monsoon. The Northeast monsoons bring water vapor from the sea and are again blocked by the Northern Truong Son Mountains Range and create a Rain Shadow Effect (Fig 2.15).

Vapor accumulated, causing long lasting rainfall, annual average rainfall (Xo) is unevenly distributed in the Northern Truong Son range, varying from 1,500 mm to over 4,000 mm. Heavy rain centers (Xo> 3,000 mm) appear on high slopes and receive moist monsoon, which formed by the North Truong Son Range in the West and Bach Ma Range in the South such as the Tra My rain center (Quang Nam, 2400 – 4000mm), Nam Dong (Hue, 2400 – 3600mm), Ba To (Quang Ngai, 2400 – 3600 mm), etc. In particular, Bach Ma rain center reaches over 4,000mm. The annual rainfall of Bach Ma can be up to 8,000mm in 1998 (General Statistics Office of Vietnam).

Annually, there are 120 - 200 days of rain (200 days in A Luoi, 120 days in Quy Nhon). The monthly average is about 10 - 20 days with rain in rainy season and 5 - 15 days with rain in the dry season. In the north of Hai Van pass, during the winter - spring months, the coldest waves of the Truong Son range are blocked cause drizzling, which makes the number of rainy days in the month is quite high (10 - 15 days). The number of days with rainfall greater than 1mm is from 130 to 170 days per year. However, the total number of rainy days (> 50mm) is not much, around 6 - 8 days per year. The number of days with heavy rain (> 100mm) is 1- 3 days per year.

Irregularly distributed rainfall during the year was the main cause of floods during the rainy season (1996, 1999) and droughts in the dry season (1997, 1998, 2000).

Fig 2.16 showed that from 2002 to 2014, the total rainfall in 2007, 2008, 2009 and 2011 at Vinh, Hue and Da Nang rain gauge stations was higher than in the remaining years. In 2011, at Hue station reached 4481mm and Da Nang was 3647.8mm. The highest in 2010 at Vinh station obtained 2716.5mm. Only in Hue station, the total rainfall in 2007-2011 obtained 19387.1mm, equivalent to 48.32% of the total rainfall in 13 years. Considering the total rainfall of all 13 years, at Hue station is the highest, reaching 40121.30mm (more than 40m hight of water) compared with 30600.3mm of Da Nang and 25208.6mm of Vinh station. Rainfall is concentrated in the months from September to December, accounting for over 70% of the total rainfall of the whole year (Fig. 2.17, 2.18, 2.19, 2.20, 2.21) (General Statistics Office of Vietnam).

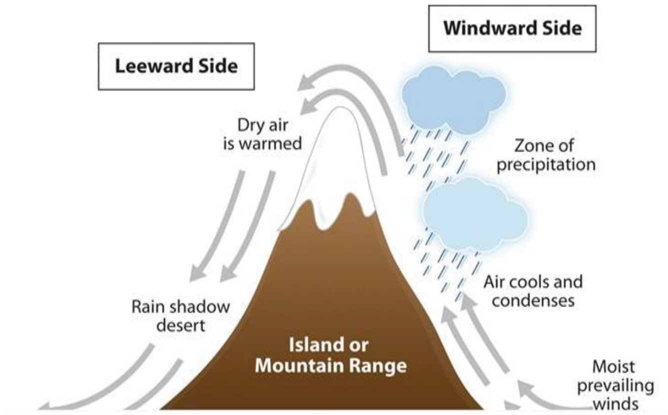


Fig.2. 15 High mountain ranges can create a Rain Shadow Effect

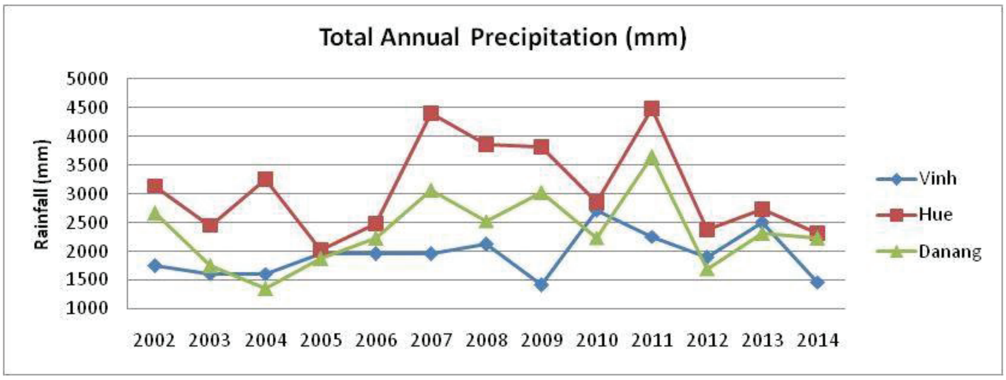


Fig.2. 16 Total Annual Precipitation in Vinh, Hue and Danang stations (mm)

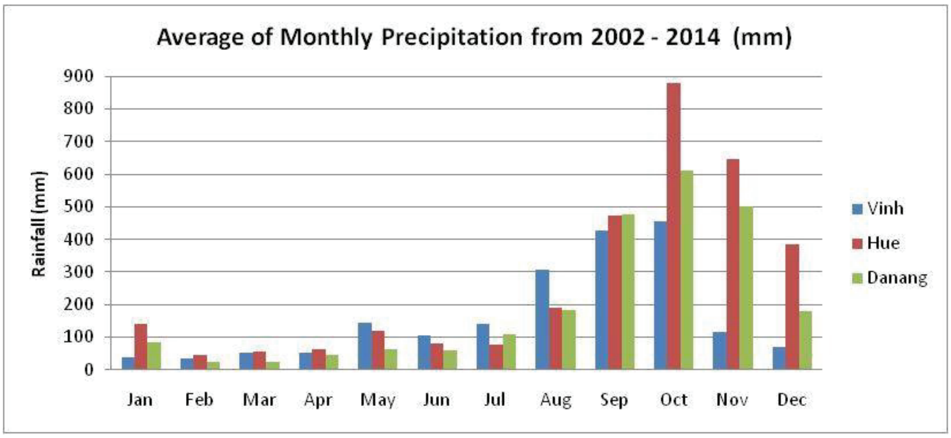


Fig.2. 17 Average of Monthly Precipitation from 2002 - 2014 in Vinh, Hue and Danang (mm)

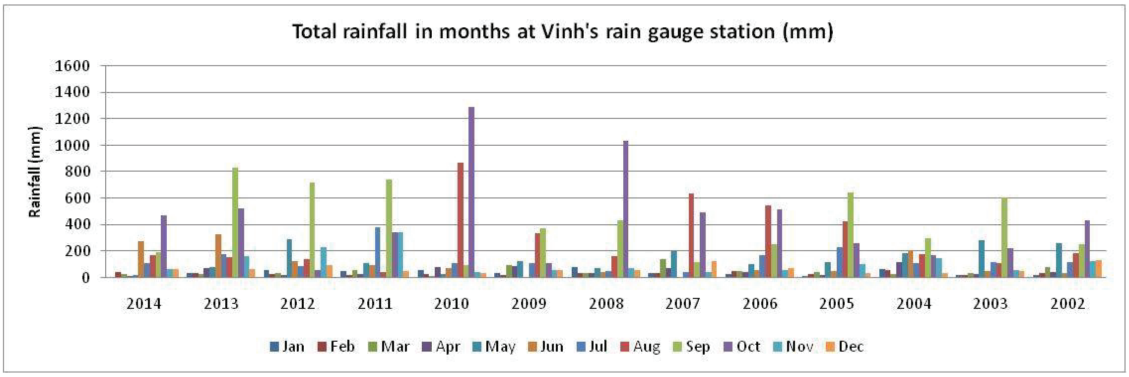


Fig.2. 18 Total rainfall in months at Vinh's rain gauge station (mm)

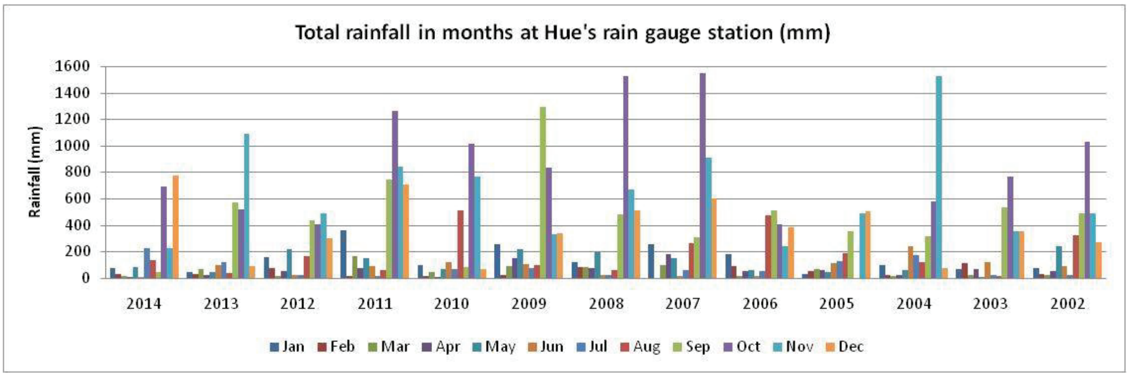


Fig.2. 19 Total rainfall in months at Hue's rain gauge station (mm)

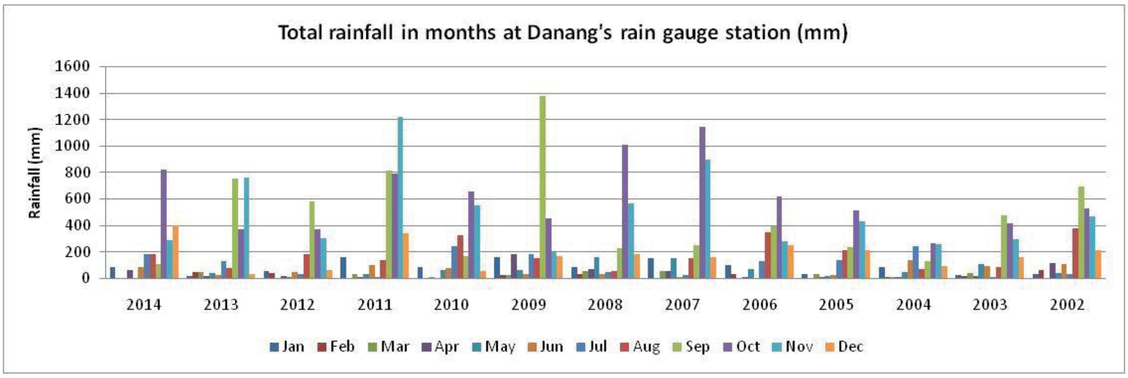


Fig.2. 20 Total rainfall in months at Danang's rain gauge station (mm)

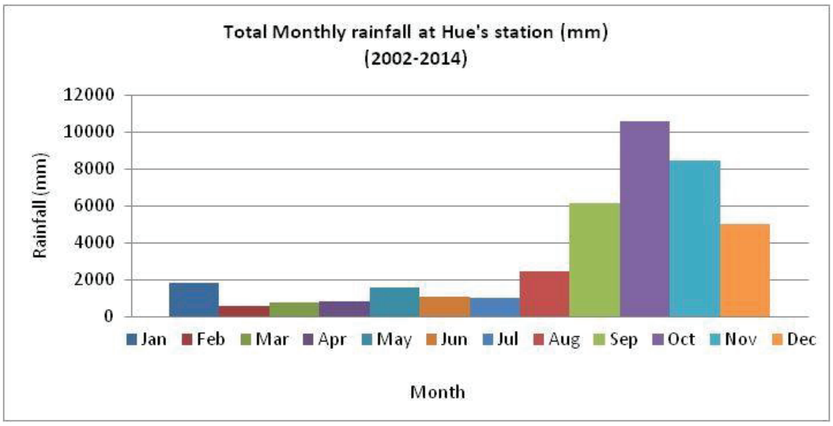


Fig.2. 21 Total monthly rainfall at Hue's rain gauge station during 2002-2014 (mm)

2.2.1.4 Underground water:

When rain is occurring, a portion of the rainwater is formed into surface water and surface runoff, and a part of the water is absorbed to form groundwater. In case of heavy rain for many days, groundwater activities that surge unexpectedly beyond the permeability of the soil layers will form underground flowing in the soil and cause erosion. In addition to the manifestation of long-term changes in rock durability in a mechanism similar to crustal weathering, groundwater at times of adverse effect has the following immediate impacts: increasing the weight of the rock mass, reducing the shear strength resistance which is mainly the cohesive force, creating hydrostatic pressure and underground erosion, etc. These physical and geological factors contribute to the increase of the torque causes slip and change the limiting condition of the soil mass.

2.2.2 Topography and Geomorphology features.

The territory of Vietnam is shaped “S”. The East and South border the South China Sea with over 3,260 km of coastline, in the north by China and in the west by Laos and Cambodia. The geography extends 1,650 km North-South but narrows East-West (the most narrows part is less than 50 km).

Most of the territory of Vietnam is mountainous, which accounts for about three-fourths of the area, the rest is plain. Mountainous system is clearly grading, 70% of the area with the height of 500m or less. 85% of the mountainous areas are less than 1000m, 14% over 1,000m, 1% over 2000m (Fig 2.22). This is the reason for determining the basis of Vietnam's natural geography that is tropical, 500-600m or more transfers to subtropical belt. The topography and geomorphology of Vietnam can be divided into three main regions: North East, Northwest and North Central, Southern and Southern Central.

The Northeast is mainly low hills with an average elevation of 600-700m. The topography is high classification consisting of two main components: hills and plains. Mountain hills account for about two-thirds of the area, mainly in the north. The Delta occupies about one-third of the area, mainly in the South and Southeast. The mountain ranges mainly follow the bow and fall from the North West to the Southeast. They spread out like fans that the Northeast monsoon infiltrates inland and Northern delta. The northeast mountainous terrain consists of seven main mountainous areas (Fig 2.22).

- Low mountainous terrain - folded Cao Xiem - Yen Tu. The Cao Xiem (1500m) and Yen Tu (1,000m), the lowland mountains are known as the Dong Trieu bow, near the West-East, to the Eastnorth, which is inverted due to a Mesozoic site raised quite strongly in the tectonic system of the vertical fault system. The slopes are in the form of steps (cuesta) because rocks have different durability with the weathering denudation process.

- Low folding mountain - An Chau block. Basically, this region coincides with the Mesozoic depression, with the East-North folds. The northern part is convex folding mountains, which improves the tectonics to show the lines dividing the old rocks. The southeastern part is relatively lower, including the valleys (Dinh Lap, Son Dong).

- The low mountain area - folded That Khe consists of Ha Lang, Bac Son, Na Sam blocks. It is characterized by karst topography with mountain blocks, equal peaks, cuesta slides, remnant mountains, deep valleys, with the appearance of convex folding Paleozoic rocky mountain due to long karst erosion. In Na Sam, the ranges of hills on the Mesozoic structure are distributed with the disorientated division down to 400-500m.

- The lowland - medium masses - folded Gam - Ngan Son. It consists of three parallel mountain ranges with an arched direction towards the east of the Gam River, PiaBioc and Ngan Son (commonly known as Gam River and Ngan Son bow) separated by valleys coincide with the Day River and Cau river faults. At the axis of the PiaBioc range, Mesozoic granite has the largest shape and the highest elevation (1500 - 1900m). Ngan Son (commonly known as Gam River and Ngan Son bow) separated by valleys coincide with the Day River and Cau river faults. At the axis of the PiaBioc range, Mesozoic granite has the largest shape and the highest elevation (1500 - 1900m). The Ngan Son bow lasts over 100 km, in the north it is reversed with the rise of the Mesozoic basin, while in the south it is in favorable terrain due to the elevation of Paleozoic convex folds.

- The low mountain area - folded Chay River (Song Chay). The Paleozoic structures here that are fragmented into isomorphic masses due to faults, which are elevated and differentiated, are stable. The water droplets of the sunken area with convex and concave folds, paint, do not coincide with the geological structure due to non-inherited tectonic origin.

- Medium mountain - high block - Hoang Su Phi arch - Dong Van. The elevated area (2,000 m) is bounded in the south by the fault zone coinciding with the upper Lo and Gam valley. The blocks are strongly separated by narrow, the profile along the river is very steep (10-15%). The formation of Hoang Su Phi can be related to the penetration of the magna together with the inheritance of the new tectonic. Dong Van arch area can have the same origin and reverse terrain with the concave folded structures of the Paleozoic limestone.

- The Con Voi low mountain range. Con Voi is a narrow (10 – 15km) and long (100km) mountain range in the Northwest - Southeast, the highest is up to 1400 m, controlled by two faults paralleling the Red River and the Chay River. Asymmetrical topography with

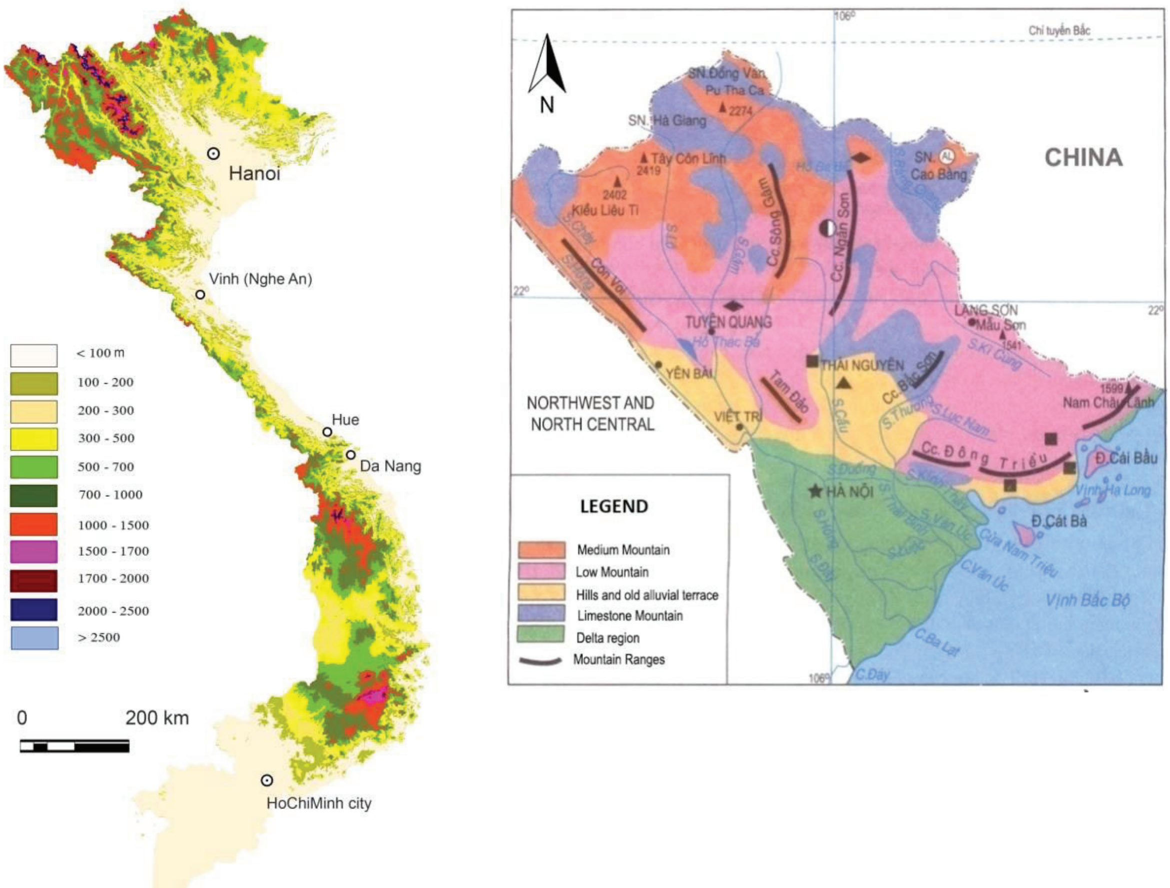


Fig.2. 22 Topographic maps of Vietnam (left) and main Mountains in the North East (right).

steep Southwest slope and strong division create distinct peaks. The Con Voi Ranges play an important role in the formation of a lineament, which divides the land of Vietnam - China with the land of Indochina. Along the Eastern flank of this mountain, an ancient river valley (the ancient Chay River) was discovered, which was looted in the Pleistocene at Nam Thi - Ban Phiet.

In summary, the Northeast terrain has been clearly observed the transition of the lifting and lowering belts, complicated by the arch lifts and the horizontal destruction zone. The method of lifting and lowering zones is reflected quite clearly in the fan-shaped hydrological network, changing from Northwest to Southeast to Northeast to Southwest. Waters most coincide with regional faults. The regional center (Chay-Gam region) is an area of relative new tectonic stability, surrounded by more distinct tectonic regions (Con Voi, Hoang Su Phi, Ngan Son, Dong Trieu)

The Northwest and North-Northern are the highest mountainous terrain in the country, including rugged, high mountains, sharp peaks, steep slopes and many canyons that move into hills in the center and southeast with low hills, the slopes, the valleys, decrease in depth and extend horizontally to transition into the Delta. The dominant mountain is the Northwest - Southeast direction, which also controls the development of mountain ranges in Thanh Hoa, Nghe An and Ha Tinh in the Truong Son Range. The terrain consists of three strips: the East is Hoang Lien Son mountain range up to 180km, 30km wide, and boundary from the border of Viet - Trung to Da River. The West is the average mountainous terrain of the mountains running along the Vietnam-Laos border from La Son to the Ca River. In the lower reaches are mountain ranges, limestone karsts and plateaus from Phong Tho to Moc Chau. Between the mountain ranges are river valleys in the same direction: Da River, Ma River, and Chu River. These characteristics of the Northwest terrain make the climate strongly differentiated by elevation and differentiation in the direction of topography. The Northwest mountain terrain can be divided into seven main mountain ranges (Fig 2.23).

- High mountainous terrain - Fansipan blocks. The area is elevated along the Northwest - Southeast parallel (more than 150 km) with steep slopes (45-55 degree), with the highest peaks in Indochina (Fansipan Mount is 3143 m high). The mountain is elevated from PZ-MZ and severely eroded by popular landslides. The mountains have asymmetrical terrain: the Southwestern slope is shorter and steeper than the Northeastern one, while the dividing line runs near the southwestern valley. The Northeast side has a hierarchical structure (1000-1600-2200 m) reflecting the stages of development in N-Q.

- Low mountainous area - folded Dong - Bieu, belongs to the conjunctive and sinking part of convex folding Fansipan. The north is the low mountains, divided by transversal valleys. The south is a large arch of Nui Bieu with valleys radiating broken rays.

- High mountainous area - Tu Le arch. The mountain lasts over 100km, 50km wide, up to 2900m high, coincides with late valley structure MZ. Younger rock eruptions which are gently sloping occupy the peaks: this is a typical reversal pattern with asymmetrical cuesta sides. The process of denudation with gravity slides grows strongly.

- Lower plateau, folded Son Moc. This plateau corresponds to the middle part of the MZ hammock, which is 180 km long, 25-30 km wide, with a typical karst topography, is limited by vertical parallel faults. On the plateau, there is a relic of the basin between the ancient mountains of the same direction (K-E age). Neogen leveling surfaces are well preserved inclined to the Da River valley.

- Medium mountainous area - folded Ma River. The area is bounded by faults, which are 200km long. Binh Son Ta Phin is up to 1900m, in terrain, near the meridian. Su Xung Chao Chai range coincides with a convex foldings; the slopes are in the form of steps. The terrain is also asymmetric: the Southwest slope is narrower and steeper than the northeastern one.

- Medium mountainous range - folded Sam Sao. The North West-South East orientated mountain is up to 1800m and is strongly separated into small, steep and asymmetrical mountain ranges.

- Medium mountainous area – high massif folding MuongTe. Northwestern part of the area is Pu Si Lung Mountain (3000 m), composed of granite. The central range is up to 2000 m high, coinciding with the concave foldings, with asymmetrical terrain, but the northeastern slope is steeper. The southwestern range is Den Dinh, 100km long, 1800m high, has a reversed topography with Kreta red sediments. An ancient river valley on the northeastern part of the range may have survived at the end of Neogen.

In the Northwestern terrain, there is an alternation between the lifting and the lower zone, which is in North West-South East direction, is complicated by horizontal or crossing zones (Lai Chau- Dien Bien zone). The asymmetric slopes of the mountains are common here because of the tectonic origin. Rivers and streams often coincide with fault systems in the area. Many cliffs are remnants of reversed faults, with the direction toward the Da River. Deeply divisive rivers, many canyons, landslides, muddy streams are quite common, strong erosion.

The Southern part of Central and South region. Typical terrain features of the Southern region are the mountains of the Truong Son Range. The Truong Son Range consists of all the smaller mountains in the Northern Central Region and the mountainous massifs, South Central plateau, forming a large bow with its convex surface facing the South China Sea parallel to the Hue Plateau. The Nam Dong area bends in a direction parallel to the Bach Ma range (Thua Thien - Hue and Da Nang boundaries). The 1500m high Bach Ma mountain range (from Hai Van Pass) running from the Lao border to the South China Sea, crosses and divides the Truong Son range into two parts, Northern Truong Son (TRUONG SON BAC) and Southern Truong Son (TRUONG SON NAM) (Fig 2.23).

The Northern Truong Son runs from the watershed of the Ca river to Quang Nam, including many parallel mountains in the Northwest - Southeast direction, the Truong Son range is closer to the coastline if it is in the South direction. There are many mountains facing straight into the sea such as Hoanh Son and Bach Ma, etc. In early Paleozoic, there is a geological area between the Kon Tum and North East blocks.

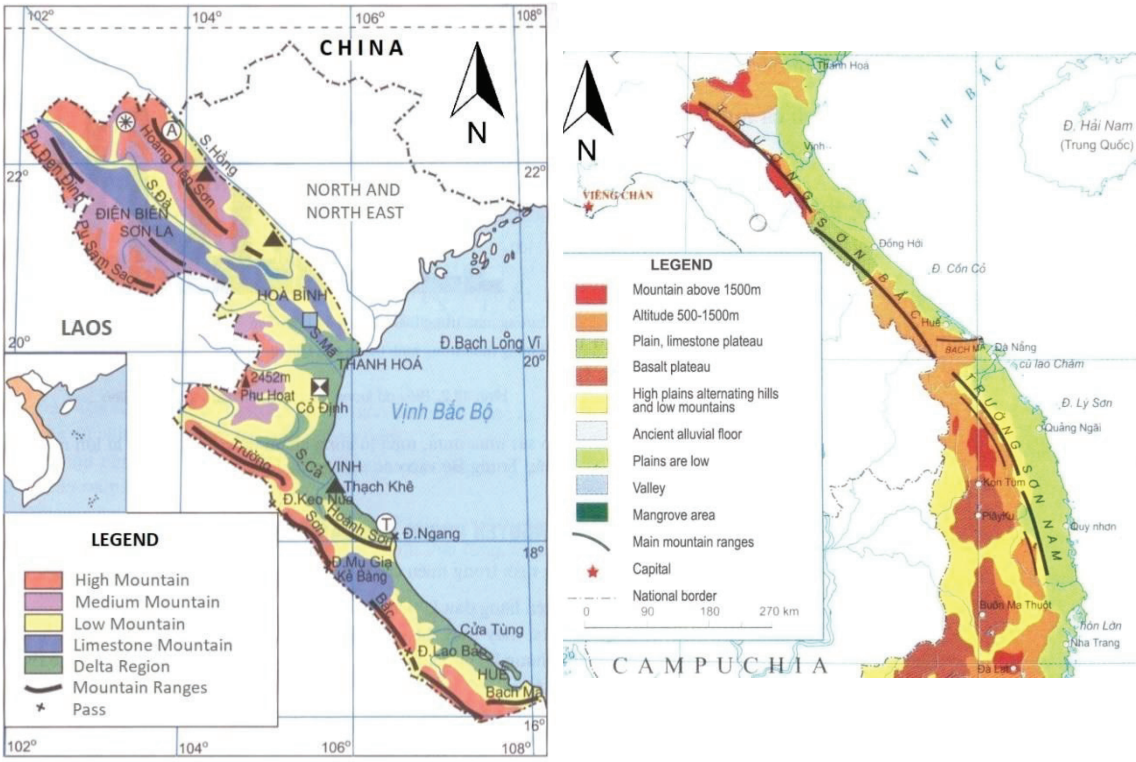


Fig.2. 23 Terrains and main mountains in the Northwest and Northern Central (left) and Topography and mountains of the Truong Son Range (right)

Hercynia foldings (250 million to 400 million years ago) created the Northern Truong Son foldings sticked to the Kontum block. After various periods of erosion and denudation in the past, the Northern Truong Son became low mountains with some leveling surfaces.

The Eastern slopes of the Truong Son Mountains are steep, and the western ones are slightly steep. The section from Vinh (Nghe An) to Da Nang, width of the plain is only 40km to 60km, the narrowest place - Dong Hoi (Quang Binh) is only about 37km.

The average elevation of the Northern Truong Son Range is about 2,000m, with some peaks over 2,500m. The highest peaks are: Phu/PuXai Lai Leng (Vietnam-Laos border, Nghe An) 2,711m, Phu/Pu Ma (Nghe An) 2194m, Phu/Pu Den (Nghe An) 1540m, Rao Co (Vietnam - Laos border, Ha Tinh) is 2,235m, Dong Ngai (Thua Thien - Hue) is 1,774m, Bach Ma is 1444m.

The Southern Truong Son is a system of mountain ranges and mountain blocks, high mountain ridges covering the eastern part of the Highlands, running from Ngoc Linh to Dinh cape. The main mountains and blocks of the Truong Son Nam are Ngoc Linh, An Khe, Chu Dju, Tay Khanh Hoa and Chu Yang Sin. The slopes of these mountains and blocks slope down to the coastal plains from Quang Nam to Nha Trang. The high terrain from Kontum to the South is Kon Tum blocks or Highlands. The high mountains in the Northern Truong Son range include Ngoc Linh (2,598m), the highest mountain in South Truong Son and more than ten other peaks (1,200m) in the Ngoc Linh, Ngọc Krinh (2025m), Kon Ka Kinh (1,761m), Vong Phu (2,051m), ChuYang Sin (2,405m), Bon Non (1692m), Chu Braian (1,865m), M'nonLanlen (1,623m), M'nonPantar (1,644m), and many others.

The mountain ridge of the Truong Son Range, as well as the water dividing line in the North West - South East with the peaks above 1000m - 2500m, which makes the Truong Son Range like a wall preventing winds from the sea, causes heavy rain in the Eastern area and Thua Thien Hue.

Due to the short, steep terrain and the deforestation by war and cultivation, it is possible to concentrate water for high speed flow in upstream areas when it rains. It will happen very quickly, threatening the plains. Due to the influence of geological elevation - central convex foldings and subsidence in the eastern margin, the Truong Son range is markedly asymmetrical. The Western slopes descend slowly into the Mekong Delta while the Eastern slopes are short and steeply slopes down to the coastal plain. From West to East, the terrain is hierarchical, the lower grades gradually towards the sea, corresponding to the gradual nature of the geological formations. The Eastern slopes are distributed at elevations ranging from 400-600m to 800-1000m.

2.2.3 Geological

The territory of Vietnam is at the confluence of two planet-sized belt - Pacific Ocean and Mediterranean. Including mainland and continental shelf, the major geological structural units of Vietnam are part of the regional tectonic units of Southeast Asia such as Sinovietnamia, Indosinia, Caledon Cathaysia folding system, Caledon Viet - Laos folding system, Thai - Malaysian Herxin folding system with Paleozoic aulacogenes, activated architectures - Mesozoic and Cenozoic multi-layered mountains that overlap on them and the East Coast of Vietnam (Luong T.D. and Bao N.X., 1980).

Geology and geological structure of Vietnam are very different in the Northern and Southern parts. Northern part of Vietnam has more Paleozoic and Mesozoic formations than the Southern part of Vietnam, and there are also many faults, with a complicated geological structure (Tien et al., 2016). It can be divided into five blocks (Tran, 1995), (Fig. 2.24, 2.25).

The oldest geology in Vietnam is the metamorphic rocks of Archean in the north west of Kon Tum province in the center part, surrounded by the metamorphic rocks of Proterozoic. Proterozoic strata layers are also found in the Northern Red River fault zone. The Paleozoic stratum is only observed from the northern to central Vietnam, all composed mainly of sedimentary rocks such as limestone, sandstone and shale. Mesozoic strata layers are distributed throughout the whole country, such as Triassic and Jurassic marine sedimentary and volcano-sedimentary rocks and cretaceous red continental formations. They consist mainly of limestone, sandstone, siltstone, shale, and conglomerate, and partially coal-bearing deposits known as Hongai flora. Granite rock distributed throughout the country includes Archean, Proterozoic, Paleozoic, Mesozoic and Cenozoic. Basalt rock erupting in the Neogene and Quaternary Era is also distributed in the western border area (Tran, 1995, JOGMEC, 2000).

2.2.3.1 The Northeast Block

The Northeast Block consists of two parts: North Northern and Northeast.

North Northern is the Southern part of China - Vietnam base. On the Baicali folded basement, it's composed of gneiss and graduate schists, developed a thickly activated overlay aged from Sini (Vend) to early Triassic with sedimentary disruptions and minor mismatches in the late of early Cambrian, late of early Ordovic, late Silur, late Devon, early of late Permian. In Ordovic, in particular, there was formed of the Phu Ngu aulacogen, which in turn expanded into the Gam River Silur basin, filled by carbonate continental sediments with acid-alkaline eruption.

North Northern region is characterized by tectonic folding, with geology or arched elevations. The activities of folding, faulting, intrusion and metamorphism in geologic and active complex - creating mountains of different periods have considerably improved.

The North East is the extension to Vietnam of the Caledon Cathaysia geologic folding system (Southeast China). In the geologically complex, only the part corresponding to the transition (end), characterized by Flys system Silurian age, is folded and in the Northeast direction. Epicaledon young layer cover including continental sediments - Carbonat Devon and Carbon - Permi is quite well developed.

The later activation stage that is characterized by the formation of the arch – Graben containing late Trias coal of well known Hon Gai and intrusion expression – late acid Jura early Kreta volcano related to the volcanic belt East of Asia margin.

2.2.3.2 The Northwest Block

The Northwest Block is the strongest broken part of the China - Viet base, lying along the edge of the China - Viet border with the Caledon - Laos geologic folding system. This region is characterized by a series of long-term, active faults that run thousands of kilometers from the Northwest (Vietnam) to the West of Van Nam (China). This can be considered as a special type of tectonic structure called the edge suture system.

On the fragments of the pre-Sini crystallized foundation, there is an activated basement complex system which is similar to that in the northern North. However, it is not only thicker, but sometimes more mafic eruption rocks like in the middle Cambrian, in Silurand in Carbon. In the subsequent activated - mountainous formation period, there was formed of the Da River riftogen arch, the intrusion basin - acid volcano - alkaline Tu Le - Fansipan, as well as the Red River Cenozoic riftogen hammocks. The North West region is characterized by folding tectonics - a linear structure in the Northwest.

2.2.3.3 Truong Son Block

Truong Son Block coincides with the Caledon Viet - Laos folding geologic system. The geologic complexes develop from the Cambrian (may be from Sini) to the end of Silurian or the beginning of the Devonian. On top of them, mid-late Epicaledon Paleozoic young layer cover was formed, as well as activated - mountainous formation arch in Mesozoic - Cenozoic.

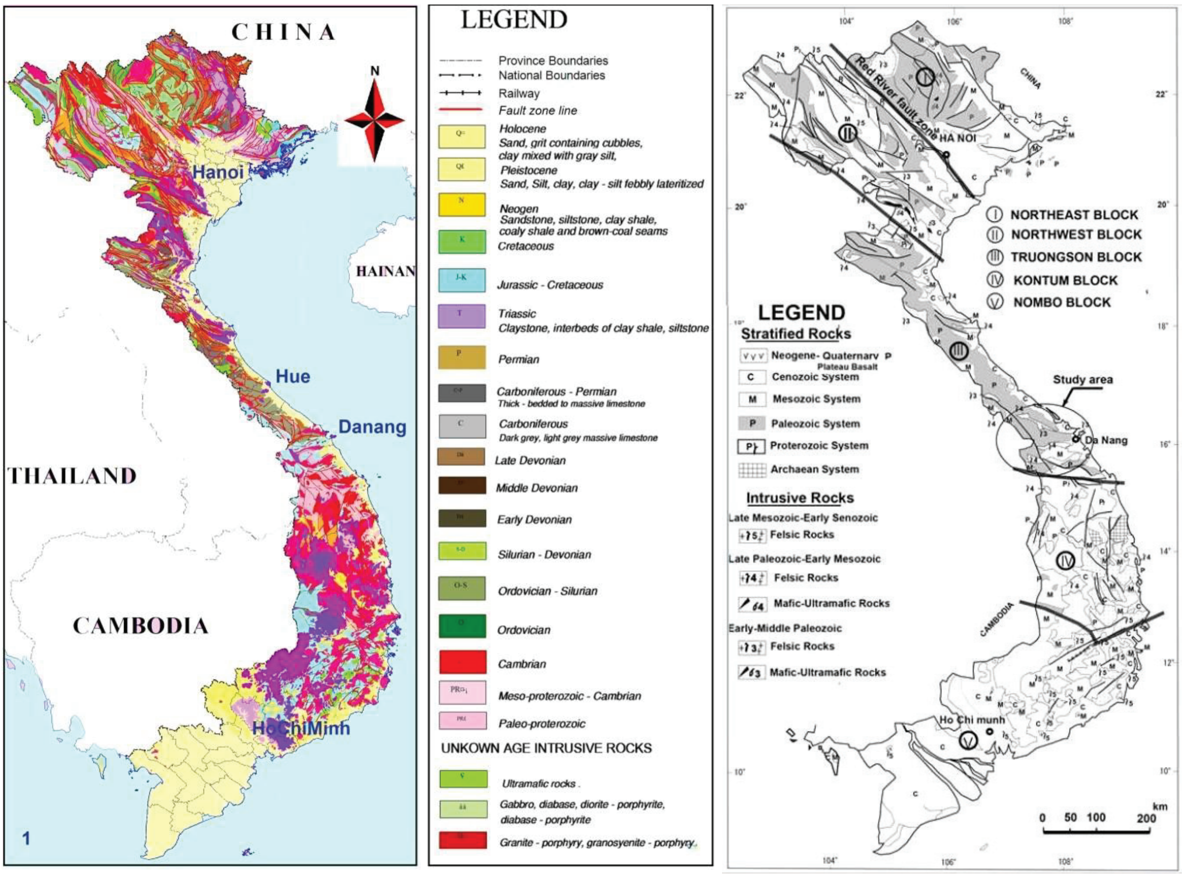


Fig.2. 24 (left) Geological map and (right) Stratigraphic division and geological mapping and major faults in the territory of Vietnam (base on Tran, 1995)

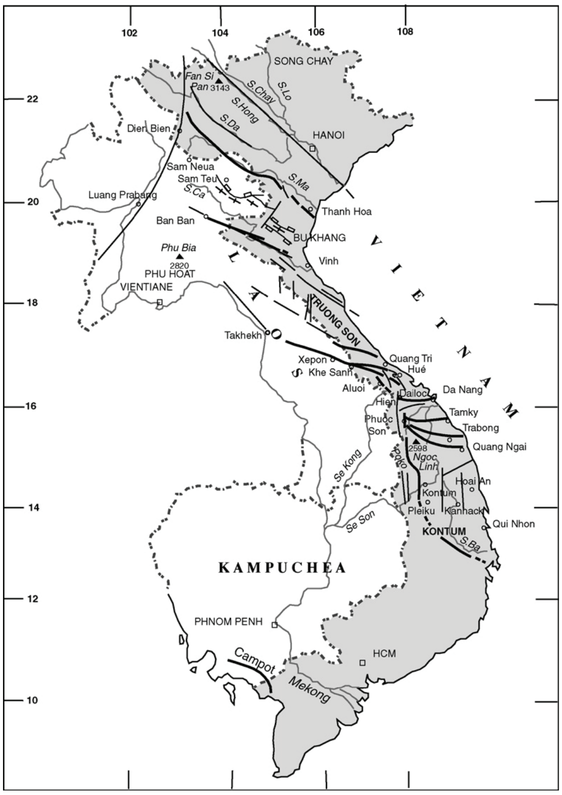


Fig.2. 25 Major Indosinian shear and mylonitized zones in Vietnam (heavy solid lines) (Claude Lepvrier et al, 2008)

2.2.3.4 Kontum Block

The Kontum Massif, in South-Central Vietnam consists of a large uplifted area of mainly metamorphic and magmatic material. Preserved granulitic rocks have long been identified within the metamorphic rocks. The magmatic formations are represented by variably deformed or undeformed granitic intrusions of Triassic age, including charnockitic rocks, and by volcanic to volcano-sedimentary Permian-Triassic rocks. Cretaceous granitic intrusions related to a Palaeo pacific subduction are present in the coastal part of South-Central Vietnam. Sedimentary rocks are poorly represented. Quaternary basalts largely cover the massif forming the central highlands (Claude Lepvrier et al., 2008).

2.2.3.5 The Southern Block

The main part of this area is the Southern geoblock of Indosinian base, where the Paleozoic cover (Saigon block), Mesozoi (Da Lat block), or Cenozoic (Cuu Long block) develop.

It is where intrusive rocks and late Mesozoic neutral - acid eruptions within the intrusion belt - the edge of the East Asia's volcano are well developed. There are also small areas in the Daklin area of the Northwestern DakLak province, which is the Eastern end of aulacogen Srepoc, as well as the Southwestern pole belonging to the Herxin Thailand - Malaysia folding geologic system.

2.2.4 Vegetation

The decline of vegetation cover affects most of the sliding factors, which can occur in the following manner: (1) Reducing vegetation cover and increasing weathering level that lead to damage the structure and the stability of soil and rock and result in potential landslides. (2) Reducing vegetation cover and increasing the risk of erosion that lead to an increase in flow rate exceeding the permeability during floods, which also destroys the structure, the sustainability and the balance of weathering and causes widespread landslides.

According to statistics, the area of forest cover in Vietnam is decreasing sharply due to unplanned forest exploitation, forest clearing for upland fields, and deforestation for construction such as roads, hydropower reservoirs, mining, etc., which have increased the risk and the extent of sliding in mountainous areas today. Fig 2.26 shows the forest cover and the level of forest cover in the Central Highlands of Viet Nam during the period 1976 - 2015.

2.2.5 Human Causes

Human are the critical factors that alter the natural conditions and make landslide hazard activate and be higher in some areas. Various construction activities have effects on natural slopes and its equilibrium such as detonation, material excavation, cutting or filling slopes, slope grade that result in losing toe of slopes, making higher and steeper slopes, etc. Meanwhile, natural slopes always tend to gently, towards the slope corresponding to the slope angle of the rock nature constituting it, ie to reach the steepest angle but then the slopes remain at steady state and no sliding. If the slope is garbled or excavated, slope angle, they will increase and stability will decrease. Therefore, when all other conditions the same, the increase of slope angle due to the impact of natural factors or artificial can cause unstable of the slopes.

Terrain shapes and the slope angle are also the main causes of landslide. The landslides often occur in sloping terrains over 25 degrees (concentrates between 30 and 45 degrees). In areas with slope angle of 16 - 25 degree, the landslides occur less and on a smaller scale, in terrain with steep slopes of less than 15 degrees, the landslides rarely or never occur (Thinh D.V, 2004).

Reality in Vietnam, road slope almost are cutting slope when it's going through the mountainous area. In statistics, more than 90% of cutting slopes are designed with a slope of 45 degrees or steeper, and many sections of the cutting slope have a height of 40-50 m or higher (Fig 2.27). However, the slope reinforced solutions are not given or not properly given, which increases the risk of landslides on these roads, in particular during rainy season.

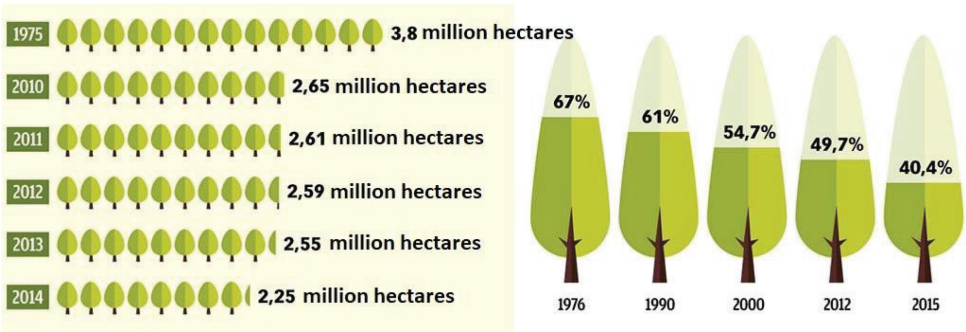


Fig.2. 26 Forest area (left) and level of forest cover (right) in the Central Highlands of Vietnam during the period from 1976 to 2015 (Ministry of Agriculture and Rural Development, 2016)

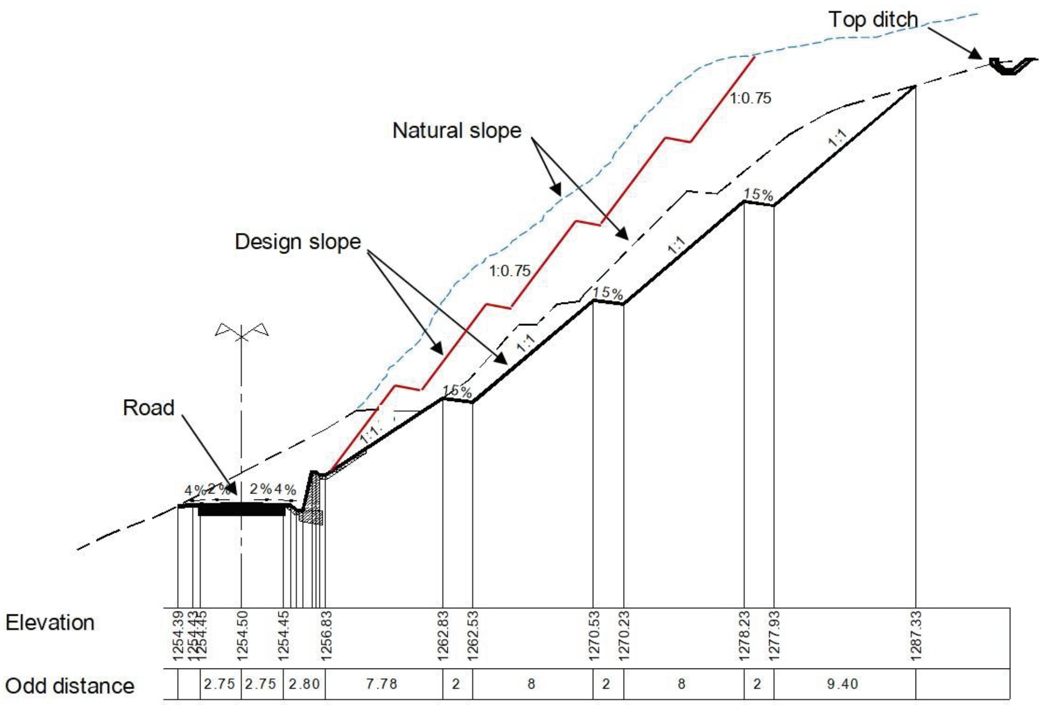


Fig.2. 27 A typical of a cross section of road going through mountainous terrain (a cutting slope)

Fig.2. 28 Cross section of cutting road on HCMR (left) and East Truong Son route (right)

2.3 Study on Landslides in Vietnam

Research on landslides in Vietnam has been early concerned since environmental incidents in the beginning in the 1980s, although this phenomenon was studied much earlier in geological perspective, for mining areas, open-air minerals, transportation works, irrigation works, etc.

In 1985, had the initial research on survey and design works to mitigate and prevent the landslides on the roads in the document named Handbook of protection and roadbed reinforced by Chat H. and Tam, D.M. The first guidelines on survey and design works to prevent landslides on the roads are issued in 1987 by MOT, entitled "Process of survey of geological and design measures to stabilize the roadbed active slide area, landslides", code 22TCN171-87. This guideline provides the basic requirements for survey and design countermeasure, including surveying for topographic, geotechnical, hydrogeology and hydrology. This material also guidelines on landslide classification, determine the main causes of phenomena, the scale and scope of a landslide project.

Next is a landslide distribution map with a 1/2.000.000 scale, it is one of the first predict research on landslide disasters (Son N.T, 1996). The landslide distribution map was updated and developed to 1/1.000.000 scale by the Institute of Science and Technology of Vietnam - MOST in 2006.

In recent years, more and more scientific and agencies' interest in geology, landslide disasters. Some project like "Surveying, evaluating the current situation, risk of landslide in some sections of HCMR, National Route 1A and proposing solution to ensure traffic safety, production and daily life of residential area" conducted by the Ministry of Natural Resources and Environment (2006-2008), "Assessment of landslide disasters in the Northern mountainous area and precautions" by Institute of Geological Sciences (2001-2003), “Landslide distribution map along HCMR” by ITST (2011-2012), the project "Investigation, assessment and zonation of landslide warning risk in the mountainous area of Vietnam" conducted by Vietnam Institute of Geosciences and Mineral Resources (2012-2015), etc.

Especially, an ODA technical cooperation project from 2011 to 2016 was 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, to train and develop the capacity for the effective use of this technology which has been implemented in Viet Nam.

2.4 Conclusion

Vietnam is one of the countries deeply affected by global climate changing. The extreme weather phenomena, causing erratic rainfall combine with human activities such as deforestation, mining, construction and transport works, etc. promote the process of geohazards, particularly the phenomenon such as the landslides, flourished with growing scale and the extent of damage is increasing and threatening the public safety.

The landslide phenomenon occurs mainly in mountainous areas. In the delta-hill area, the landslide is low, while almost of the delta area has no landslide. The landslide distribution is mainly concentrated in the Northern mountainous region, the central and Tay Nguyen region, but it is especially severe and concentrates in central of Vietnam.

Due to the characteristics of natural conditions along with the construction of new roads and urbanization, the landslides occurring on and along roads are becoming more complex and serious and affecting people's lives.

Recently, there are in-depth studies in the field of landslides, bringing positive effects on the warning and preventing this phenomenon. However, the response to this phenomenon is still passive and it is very important to continue research. Therefore, in the near future, the response and prevention of landslide in Vietnam become more active.

CHAPTER 3. THE CURRENT SITUATION FOR RESPONSE, MITIGATION, AND PREVENTION OF LANDSLIDE DISASTERS IN VIETNAM

3.1 The current Vietnamese Government's Strategy for response, mitigation, and prevention of landslide disasters in Vietnam

As one of the worst affected countries by climate change, the Vietnam government considers the response to climate change a vital issue (The National strategy on climate change, 2011). Vietnam government also considers landslide as one of the natural disasters caused major damage to human life, property, the environment, living conditions and social economic activities.

For management and mitigation the natural disasters, including the landslide disasters, Vietnam government has issued a legal framework to respond and take the initiative in managing. At present, the Law on Natural Disaster Prevention and Control has been issued and effected since May 2014. Statutes on Dike Management, Flood and Typhoon Mitigation, and the Ordinance on Flood and Storm Control have been established for flood or storm disasters (Table 3.1).

Next, the National Strategy for Natural Disaster Prevention, Response, and Mitigation to 2020 (NSNDPRM) was issued by the Prime Minister in Decision 172/2007/QĐ-TTg on November 16, 2007. It emphasizes the policy shift from disaster prevention and mitigation bases only on structural measures to a policy, including non-structural measures, from top-down to local government and community-based disaster management. Provinces preparing their own implementation plans based on the Implementation Plan of the NSNDPRM (Table 3.2).

Tab.3. 1 Laws and Regulations of Disaster Management in Vietnam (JICA, 2015)

	Laws / Regulations	**Supervisory Authority**	**Subject**
Law	Law on Natural Disaster Prevention and Control	Minister of Agriculture and Rural Development, Department of Dyke Management	Disaster Management
Decree	Decree No.168 - HDBT, 1990	Under survey	Disaster Management
Decree	Statutes on Dike Management, and Flood and Typhoon Mitigation	Minister of Agriculture and Rural Development, Department of Dyke Management	Flood
Decree	Ordinance on Flood and Storm Control	under survey	Flood

Tab.3. 2 Strategies and Plan for Disaster Management in Vietnam (JICA, 2015)

	Laws / Regulations	Supervisory Authority	Subject
Plan	National Strategy for Natural Disaster Prevention, Response, and Mitigation to 2020 (2007 - 2020)	Minister of Agriculture and Rural Development, Department of Dyke Management	General Disasters
Plan	Implementation Plan of the National Strategy for Natural Disaster Prevention, Response and Mitigation to 2020, 2009	under survey	General Disasters
Plan	Plan of operations of Vietnam National Committee on International Decade for Natural Disaster Reduction (IDNDR)	under survey	General Disasters

NSNDPRM is an implementation plan issued in 2009 as the guidelines for other ministries/agencies and local governments to apply according to local situations. Provinces prepare local implementation plans following this national framework. Fig 3.1 shows Disaster Management Structure in Vietnam.

A hazard map for landslides and related laws are under development. There have been pilot projects for an early warning system for landslides. However, the system has not yet performed effectively. The practical activities for risk assessment and vulnerability in local areas are not sufficient.

There are several projects for the early warning system, the study of landslide records, and risk management for the landslide are on-going.

3.2 The current Manuals for response, mitigation, and prevention of landslide disasters

Although the researches and application for responding, mitigation and prevention of landslide disasters in Vietnam started early, but so far, the guideline is considered to be the most specific service for treatment project on landslide is a National Standard, named as "The landslide prevention engineering on road Requirements for Investigation and Design", code TCVN9861:2013 (known as Standard TCVN 9861:2013), issued by Ministry of Transport.

This Standard prescribed the basic requirements for survey and design countermeasure, including surveying for topographic, geotechnical, hydrogeology and hydrology. This Standard also prescribed on how to classify landslides and determine the main causes of phenomena, the scale, and scope of a landslide project.

Contents of the standard, including general provisions on application scope and define some terms used in the standard. Guidelines and regulations on landslides classifications instructed and regulations in the survey works of topographical, geological, hydrological, and hydro-geological. Finally, requirements for landslide survey profiles and regulations for design, inspection, and acceptance of the landslide prevention countermeasures. Fig. 3.2

shows the current workflows for implementation of a landslide project in Vietnam.

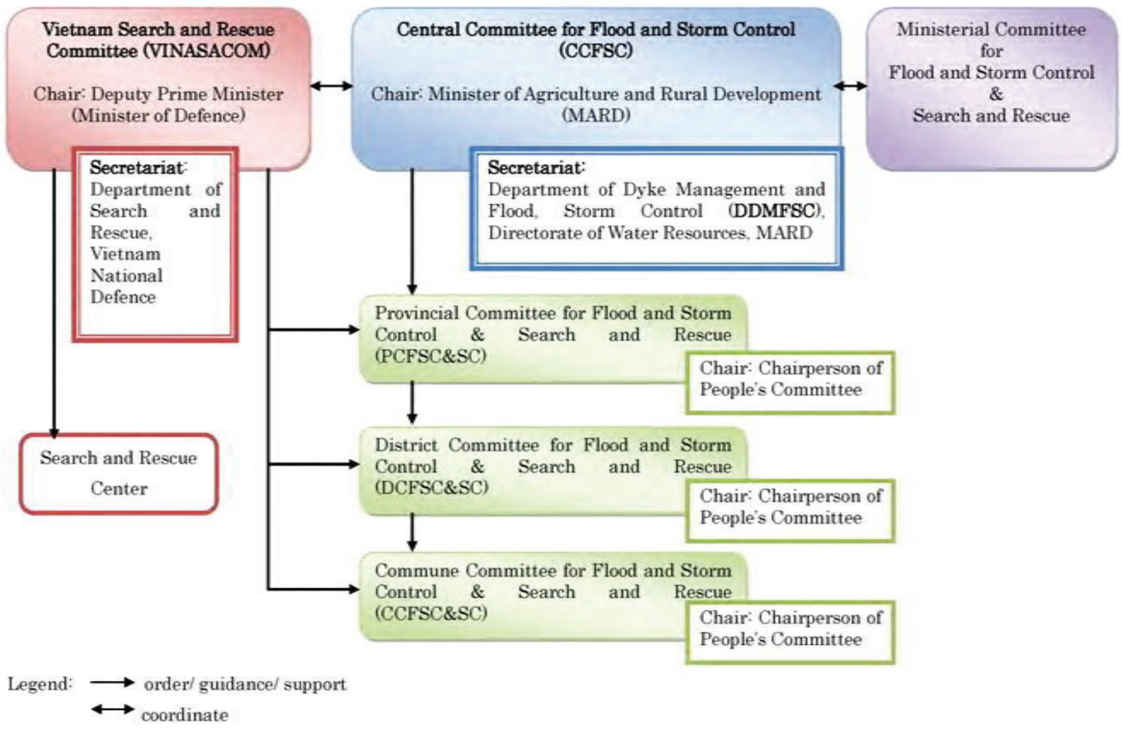


Fig. 3. 1 Current Disaster Management Structure in Vietnam (JICA, 2015)

3.2.1. The current manual for landslides classifications

A series of methods and systems of landslide classification have been proposed with different perspectives by authors under their study fields.

For instance, based on the type of movement of rock and soil on the slope, landslides should be split into 4 types such as landslides, flow sliding, collapses and rockfalls (Ngoc N. S, University of Transport and Communications, 2006).

One other use is classified based on the method of V.D Lomatadze (1997), there are 3 types such as structure sliding, plastic sliding, and plastic - structure sliding (Ty P. V and Thang L. T, Hanoi University of Mining and Geology).

Hai D. H and Chat H. (2002) from the National University of Civil Engineering have proposed a method for landslide classification occur along roads, landslides can be classified by three main types such as landslides, slides, and drifts. Each of these main types can be divided into some details types depending on the characteristics of geology, direct reasons for movements and scale of hazards. The landslides, including rockfalls, collapse with soil or rock material or debris and rock topple and earth fall. The drifts can be divided into disturbed drifts and non-disturbed drifts.

Thu T. M and Uyen N. (Hanoi Water Resources University, 2010) classified landslides by three main types such as collapses, slides, and rock falls. Slides can classify as translational sliding, rotational sliding, and flow. Rockfalls can classify as rock slump, rock spread, and rock topple.

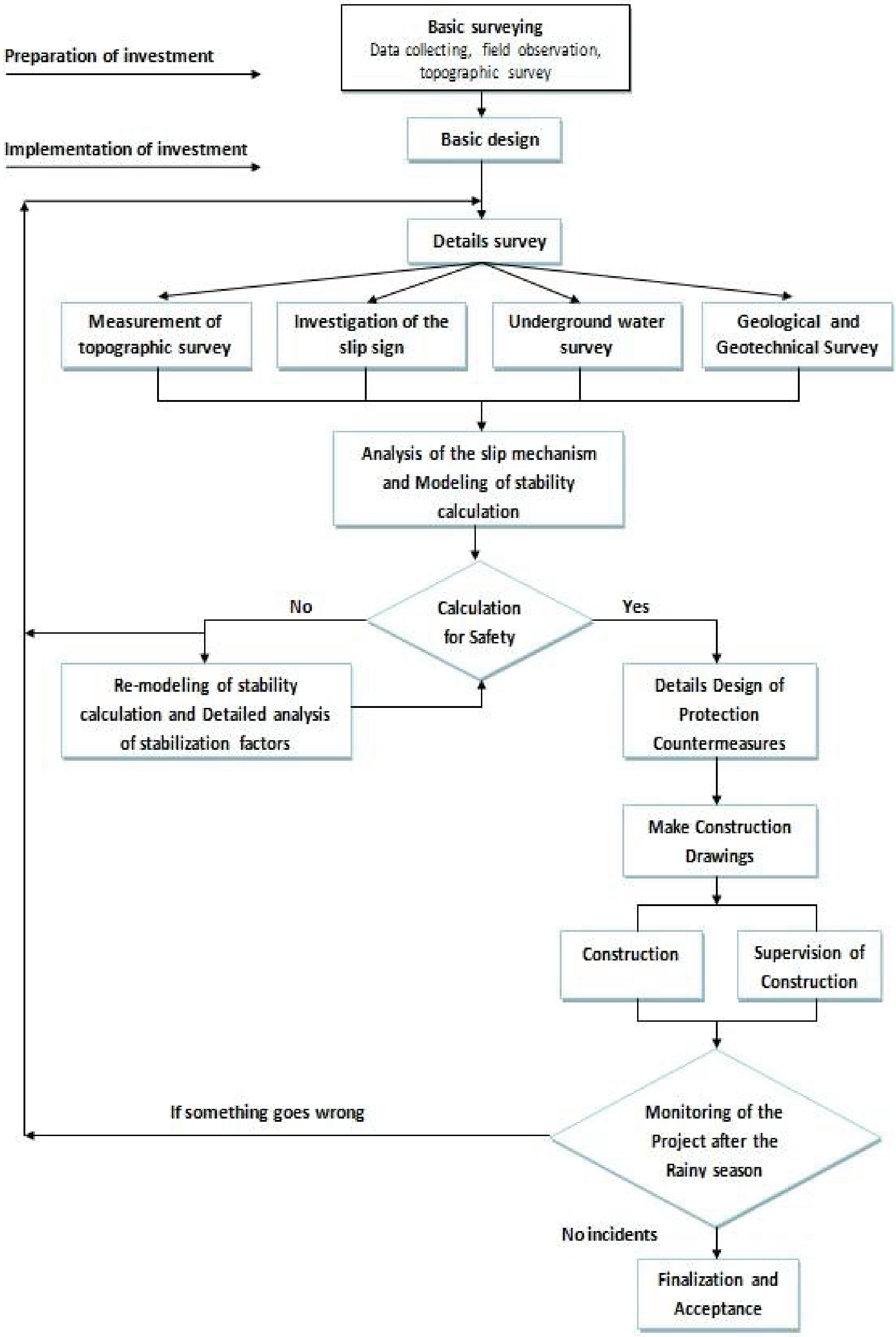


Fig. 3. 2 Current Workflows for Implementation of a Landslide Project

Nevertheless, there are two major ways of landslide classification, which were proposed by Chat H. and D.M. Tam in Handbook of protection and roadbed reinforced, that are classified by type of movement and by scale. Classification flowed these ways also have been accepted and used in National standard TCVN9861:2013.

3.2.1.1 Landslide classification by type of movement

Based on the characteristics of slope failures on roads, the Standard TCVN 9861:2013 classifies landslide phenomenon into landslides, collapses, erosions and flows and rock falls.

Landslide: It is the phenomenon of moving the rock mass on a slip surface, usually with a rotating cylinder (when the soil in the mass is relatively homogeneous and when the slip surface extends into the underlying rock or slides along the plane of bedrock). It is considered that when this landslide active, all entire soil is moving at once, the rock in the slump is fewer disturbances. Trees or structures on the surface are tilted and move together with a corresponding distance and leave a clear main scarp or minor scarps on the topographic surface. Depending on some other signs in the mechanics of slide, there are some subsidies such as old landslide, deep landslides, shallow landslides, flows, and slides along the plane of bedrock.

These phenomena are most popular in the steep hills or adjacent areas of material excavations. The volume of landslides is about several hundreds of millions of cubic m, often occur along North-West routes, HCMR and other national highways in the Central area, and in some places, notably the provinces of Hue, Quang Tri, Ha Tinh, Quang Nam, Quang Ngai, etc. Rotational landslides often occur on cutting slopes or filling slopes that have quite a homogeneous geological structure such as Da Deo Pass, NH6, and HCMR. Fig 3.4 (left) was a landslide caused emerges of pavement on HCMR.

Other landslides with transitional or segmental surface occurred in some parts of HCMR, NH1A depending on the shape of bedrocks. This type has the largest scale and occupies only 10-15%, but the most serious and complex of the remedial measures (Tam et al,, 2008). Landslides usually have some or all the evidence of characteristics such as head, crown cracks, scarps, minor scarps, main body, the surface of rupture, crown, transverse ridges, foot, radial cracks.

Collapses: Collapses often occur in rainy seasons and damages not serious, but very frequent and widely spread. This type of landslide occupies 60% and distributes along some roads such as NH7, NH8, NH9, NH21, NH14, NH19 as well as HCMR (Tam et al,, 2008). Collapses usually have some or all the evidence of features such as steep scarps and have no a surface of rupture. Rocks in the slump are disturbed or loose and have no a crown, no deep cracks, and no transverse ridges. The soil is mixed water and the trees are poured down (Fig 3.4, right).

Erosions and Flows: This type occupies 20% on roads and often occurs as a mixture of materials and the flow of water, caused by heavy rain poured from the upper basin or a combination with the effects of groundwater flow. Landslide cutting the channel side, there is an appearance of soil erosion phenomenon at first, then the mass of earth detach from the top of slopes and failure gradually develops downward along the flow and is in direct proportion to flow velocity. Flows are very dangerous with considerable and long-term consequences by causing the damage of infrastructures, sweeping away properties or burring residential regions. Erosions and flows usually have some or all the evidence of characteristics such as steep scarps, do not have a surface of rupture and the main body. Rock on a slope is loose, forms cavities and gullies. It only occurs when having a flowing of water (Fig 3.5, left).

Topples and Rock falls: This phenomenon occupies 5% and commonly occurs after prolonged rains or during the rainy season along routes in the north-west region and on HCMR in the Central Coast region. The rock volume is not large, but it is very dangerous and likely to cause accidents or traffic jams.

Topples and rock falls usually have some or all the evidence of characteristics such as scarp is rock. Rock is stratified and layered with a sloping angle downward to the road. It is strongly fractured, has streams and fall on the road (Fig 3.5, right).

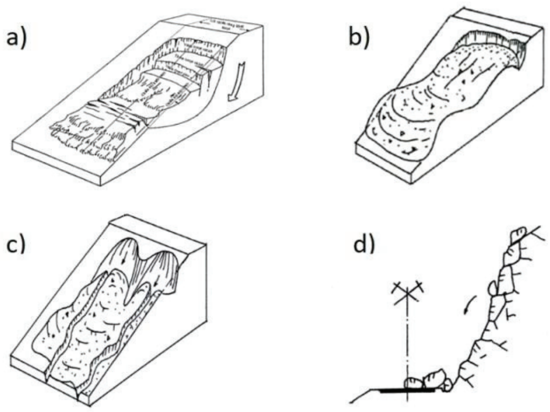


Fig. 3. 3 Landslide classified by type of movement (Standard TCVN9861:2013) a) landslide, b) collapses, c) erosions and flows and d) rock falls

Fig. 3. 4 Landslides caused emerge of pavement (left) and Collapses (right) on HCMR

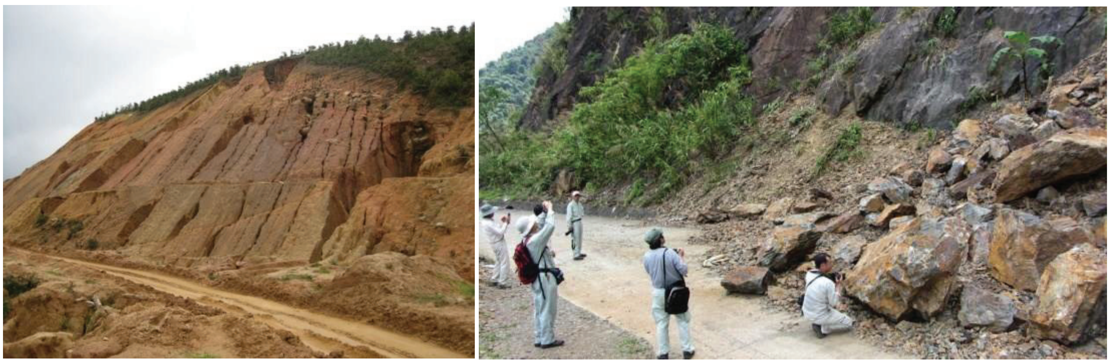
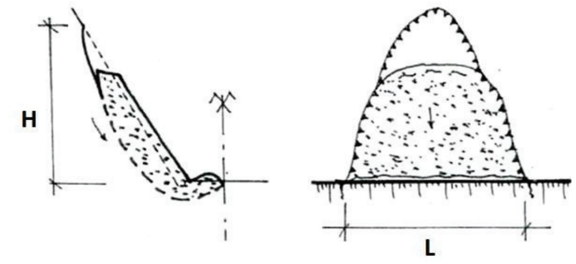


Fig. 3. 5 Erosion often occurred on Truong Son Dong route (left), Topples and rock falls on HCMR (right)

3.2.1.2 Landslide classification by scale

By scale, a landslide can classify to 4 types such as small, medium, large and very large scale, depending on landslide size and degree of influence on the traffic situation (Table 3.3). According to the statistics, the small and medium scale of landslides occurred along routes occupy up to 60%, main caused of economic losses and have a direct effect on traffic and people's life (Tam et al,, 2008).

Tab.3. 3 Classification of landslide by scale (Standard TCVN 9861: 2013)

Scale of landslides	**Size of landslides**		
	H (m)	L (m)	
Small	H ≤ 10	L ≤ 20	
Medium	10< H ≤ 20	20< L ≤ 50	
Large	20< H ≤ 50	50< L ≤ 100	
Huge	H > 50	L >100	

3.2.2 The current manuals for landslide surveying

Current manuals used for surveying topography and geology for a landslide project are still basically used in conjunction with the guidelines for the road project construction going through complicated geological areas, which was issued by the transport sector. Apply these guidelines as used for survey and design road on the soft ground. That is National standard named "Highway - Specifications for Design", code TCVN 4054-2005; a sector standard named "Specification for surveying geological conditions and designing stabilized method for embankment in the landslide and settlement area", code 22TCN 171-87; a sector standard named " Process on surveying design of motorway pavement on soft soil ", code 22TCN 262-2000; and National standard "The landslide prevention engineering on road Requirements for Investigation and Design", code TCVN9861:2013.

Standard "TCVN 9861: 2013" is considered to be specific to landslide project, and has been compiled based on "22TCN 171-87", has updated many new contents, added specific surveying regulations on topographic, hydrographic, hydrological geography, but still lack the guidelines and the methods of implementation, so it is difficult to apply the application in an efficient way.

3.2.3 The current manual calculation and design for prevention of landslides

As a standard "TCVN 9861: 2013", slope stability coefficient could be calculated by methods of Fellenius, Bishop, Goldstein, etc., for the cylindrical sliding surface, by methods of Sakhunhian, Maxlop - Berer, etc., for polygonal slip surface and combined above methods for the mixed sliding surface.

Based on results analysis of the stability coefficient (K_{od}) of slopes, the stability of the slope will be evaluated. The calculation stability coefficient (K_{od}) will be compared with a standard stability coefficient (K_{tc}). If the condition $K_{od} \geq K_{tc}$ is satisfied, the slope is considered to be stable. Almost in these cases, the slope is no need to use any treatment solutions. And if this condition is not satisfied, one of the solutions for mitigation and prevention would be considered. The standard stability coefficients are specified and depending on the significance of the route and specified in Table 3.4.

Tab.3. 4 Value of standard stability coefficient (K_{tc})

	Cases of assessment slope stability	**Value of standard stability coefficient (K_{tc})**
1	For expressway	1.30
2	For highway class I, II	1.25
3	For highway class III, IV, V, VI	1.20
4	For local road (Provincial road)	1.15
5	For rural road	1.10

3.2.4 Current solutions for mitigation and prevention on landslides in Vietnam

After receiving information about a landslide occurred, as quickly as possible, the Road Management Unit will conduct the inspection of the field and clean up debris on the road in order to ensure smooth traffic. If the landslide completely breaking traffic artery, it will be reported to the competent authorities (Ministry of Transport) and a recovery project will be quickly set up. Other cases will be collected and statistics on the annual landslides list by Regional Road Management Unit and the Province's Department of Transportation. Each year, these agencies will submit proposed plans to DRVN to recover and control these landslides. Depending on the importance of the road, the scale of damage, the prevention funding source, the ability to ensure the quality of construction, DRVN will consider arranging implementation priorities and approving the treatment solutions.

Three groups of solutions for landslide prevention and mitigation along roads in Vietnam are applied, such as temporary solutions, semi-solidifying solutions and permanent solutions (TCVN 9861: 2013).

The temporary solutions are used for the provincial road or national highway that have low traffic volume and less important. The purpose is handling temporary situations to ensure traffic quickly and accept the situation of landslides continues occurring. It includes cleaning up materials, debris, excavating and filling to the slope, or installing some gabions or building some small retail wall segments, etc. The advantages of this solution are very fast in construction, cheap, materials available locally and do not require high technology that multiple constructors can do. However, the limited is treatment outcome not thorough, potentially of landslide occur anytime, so always keeping monitoring unit and handle.

Semi-solidifying solutions are often used for the provincial road, national highway not so important (inadequate important) and average vehicle density. These solutions combined cleaning up materials, debris, excavating and filling to the slope, building drainage on the surface of the slope and construct other engineering works, etc. The advantage of this solution is funding for implementation is consistent with maintaining capital repair annually. Many contractors have the ability to perform due to technological requirements are not too difficult and can be combined the advantage of local materials and local labor. However, the processing results are still not fully completed, the landslide still maybe occurs when raining heavy, causing damage, prejudice and traffic disruption.

Permanent solutions are used for national highways with high vehicle density and importance. When a landslide occurs, it can cause a major damage to life and property, transportation artery rupture or have a direct influence on the extremely important works around. In terms of these solutions, permanent works can be applied new and high technology to achieve high levels of sustainability, capable of preventing or handling landslide phenomenon thoroughly and ensuring smooth traffic during the year. These solutions have the advantage that the results are thoroughly treated as well as the sustainable works during calculation time. However, the disadvantage is a big capital investment required (often many times more than other solutions), high technical requirements, new technology, much complexity, few materials and local labor can be used. In addition, lack of experienced professionals, lack of standards and technological processes as well as the problems while applying these solutions. Moreover, due to the complexity of the technology could be limited to a small number of qualified contractors performing.

Reality in Vietnam, temporary and semi-solidifying groups are primarily applying, so landslides continue to occur to damage prevention works and have an influence on traffic disruption after every rainy season. These solutions primarily apply some simple countermeasures such as concrete walls, reinforced concrete with bored piles or steel pile foundation, drainage construction and sloped surface reinforcement, etc. Application of new technology, new materials for landslide mitigation and prevention are still in the researching, construction of the pilot.

The annual budget for disaster prevention reaches only about 30% -40% compared with on-demand, also lacks the guidelines and the experts so permanent solutions group almost have not much been applied.

3.3 Limited of current Manuals for mitigation and prevention of landslides

The Standard TCVN9861: 2013 is specified steps in a landslide treatment project. However, the actual implementation still reveals the limited contents. Some specified in this document remain not details and clear yet, which makes the engineers find difficulty using and confused in choosing the solutions. Therefore, many reinforced works, despite having survey, are designed and constructed as stipulated in the standard, but still not thoroughly, re-damaged or destroyed after only one or a few rainy seasons (Tam et al,, 2008).

First, classifications based on the classification of Varnes (1978) are widely recognized and used in many countries. It considered a complete classification which is simple and easy to use. Recent updates on the classification based on the classification of Varnes (1978) and Cruden & Varnes (1996) were used by scientists and the International Consortium on Landslides (ICL). By type of movements, Varnes divided into 6 main categories: fall, topple, sliding, lateral spreading, flow and complex sliding. By materials on sliding blocks, it can be classified details of 29 different types (Table 3.5).

Followed the classification of Varnes (1978), there were 6 types of landslides observed base on 182 landslides along HCMR: 1) translational rock slide, 2) rotational slide, 3) rock fall, 4) translational wedge type slide where a moving mass slides in a triangular form, 5) translational shallow debris slide where debris of thickness under one meter slide down the bedrock, and 6) gully type slide and flow where an arc-shaped sliding mass originates at the upper area of a slope slide down the slope surface, and the morphology resembles an erosional gully (Abe et al., 2014) (Fig 3.6).

Although four types of landslides classified in Standard TCVN 9861: 2013 are the majority of transport arteries in Vietnam but do not reflect all the phenomena. Complex landslide and flows sliding also often occur on the mountainous roads such as NH279, NH4D, NH37, NH34 and on HCMR, etc. Flows sliding characterizing the movement of materials on body landslide forming lines with different moving speed from very slow to very fast. Products can be the mixture of sliding rocks with water (debris flows) or the dry material. Debris flow is one type of landslide hazard risk, spread risk in Northern mountainous provinces and the Central coast area.

When the classification of landslide fully and consistently with the general classification of the world will bring many advantages in sharing information, experience, acquisition, transference and effective application of research and scientific and technological achievements of the world in the mitigation and prevention on landslides in Vietnam.

Tab.3. 5 Landslide classification according to the materials on sliding blocks (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

Second, the requirements and regulations for the survey have no distinction in terms of type and scale. About landslide forms, the survey activities for a rock fall, debris and deep or shallow landslide, etc. are the same requirements. For the scale of landslides, the survey activities for small-scale with large-scale, very important or less important points, and when the landslides have not yet occurred or happened have no difference. It is clearly inadequate. It may not be feasible or cause unnecessary waste.

The preliminary step topographic survey, the Standard TCVN 9861:2013 requires must have the landslide area map with contour lines of an interval of 1 meter. If the landslide is small or medium scale, it can easily conduct. Nevertheless, this is not easy and feasible for the craggy terrain area or spreading out a huge area, especially in the preliminary investigation step.

In fact, field investigation for determining the scale and scope of sliding mass, main scarps or minor scarp, the main body of the landslide, etc. are very difficult and complicated. If there are no special methods to implement, not anywhere, engineers can easily access to the recognition, measurement, digitize, or field experiments for samples, etc. Especially investigate in the craggy terrain area or very large landslides. Thus, we should have specific requirements for survey activities and perform in each stage of the survey as a preliminary survey, detailed survey. For example, with a very large-scale landslide in very inaccessible areas, the survey work will require another request with a small landslide and easily accessible. The requirement of results of survey activities at each stage should also depend on the specific conditions such as the accessible or inaccessible areas, the scale of landslides, the impact and scope of the damage, as well as the importance of the surrounding constructions. Even the different requirements of mapping scale can also save time and economic efficiency.

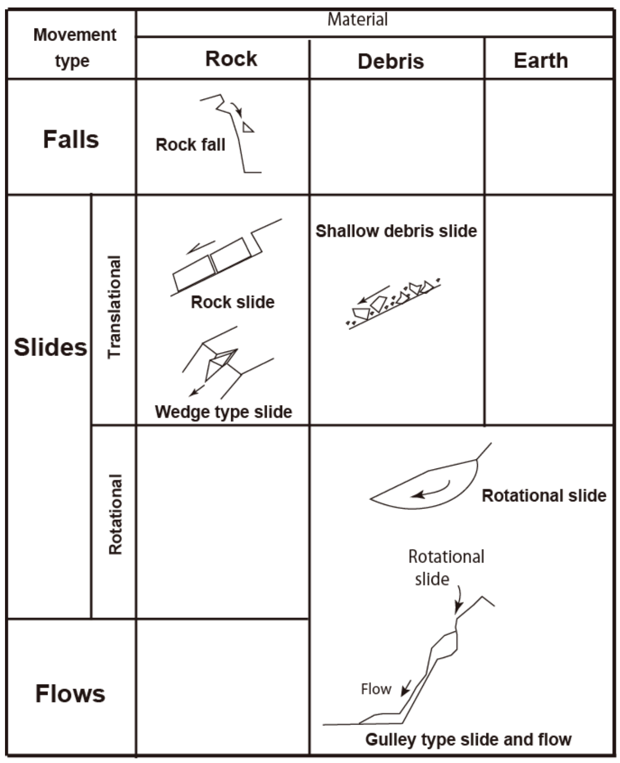


Fig. 3. 6 Moving types of landslides along HCMR (Abe et al., 2014)

Fig. 3. 7 Flow landslide on NH34 (left) and on NH7 (right)

Fig. 3. 8 Complex landslides on HCMR (shallow landslide with earth flow) and NH6 (slump-earth flow with rock fall debris)

In addition, the standard does not distinguish geological survey activities of landslide occurrence and potential landslide risk. Standards have not specified a specific requirement how to identify the real slip surface of landslides (slip plane). The most important purpose of landslide survey is to accurately locate the sliding surface. This is the same purpose of later field surveys. Planning landslide measures without knowledge of the sliding surface are very difficult, and the effect of the measures can be unexpected. Therefore, the survey must consider where the sliding surface is located. Delaying the sliding-surface estimation until a later survey is undesirable. Obtaining information about the sliding surface should be a part of the initial reconnaissance (Abe et al., 2013).

Geological survey for a landslide project is different from others. Especially the drilling and sampling methods for surveying landslides are not completely identical to the engineering geological drilling. Drilling to obtain intact core drill during all drilling depth is significantly important to consider, analyze and detect the slip surface of a landslide. The standard TCVN 9861: 2013 required taking one undisturbed sampling every 0.5 meters or 3 m of drilling depth just only suitable drawing the geological section serves for simulations assumed slip surface.

In addition, experimental work determined the materials indicators on slip surface are very important. In many current standards just require some basic mechanical properties serving for stable coefficient calculation such as cohesion, the internal angle of friction, density, grain composition, coefficient permeability. Normally, the position of the slip surface often appears in a thin layer of material which can only be thick a few centimeters, has the characteristics of the structure, composition. Moreover, the characteristics are different from the adjacent rocks at the top and bottom. Here there are signs of humidity which increases dramatically and becomes greater porosity or appears clay component or thin coal layers, or a layer of strongly weathered rock contains many ingredients kaolinite or in the part bedrock containing illite.

Many experiments or measurements should be taken in the field in the period of investigating such as soil hardness testing, Schmidt hammer test or handy seismograph test, etc. in order to investigate the distribution of geological section hardness or identify and check the slip plane. The results of field experiments and in the laboratory will make a great contribution to clarifying the characteristics of soil strength for recognizing the mechanism and estimating the slope movement.

Fig. 3. 9 An example of geological drilling for identifying slip surface of landslides in Japan

Finally, there is a variety of computer software support for calculating the coefficient stability, such as SLOPE/W, STED, MIDAS, ADCALC3D, etc., However, the results of analysis depend very much on the selection of diagram calculations, analysis methods, a variety of slip surface shapes, pore-water pressure conditions, soil properties, loading conditions and simulation software was selected.

Actually, SLOPE/W is the most common simulation software. Due to the difficulty in determining the slip surface so the circular cylindrical shape of slip surface is normally selected for simulation and calculation. In the majority of cases, cylindrical slip surface brings about several consistent results. However, in some cases, real slip surface is very different from the cylindrical shape leading to the result of calculation with significant error. In addition, the selection of different calculation methods also gains different results. When being simulated with the same conditions, stable coefficients calculated by Bishop (simplified) method are always higher than that calculated by Fellenius method about 8-10%. The difference of results between calculated by assumptions slip surface method and method of assumption underlying the force equilibrium of slide amounted to 10% (Ngu V.C, Dong P.H.). In some other standard design, when assessing the soil slope stability could allow using both methods. But the difference is the factor of stability required [K_{tc}] as 1.10-1.15 if using Fellenius method and 1.25-1.30 if using Bishop (simplified) method.

3.4 Difficulty to choose a solution for mitigation and prevention of landslides

Many solutions for the response, mitigation, and prevention of landslides would be selected, such as doing nothing, avoiding areas of the landslide, monitoring combination with some simple countermeasures, or permanent countermeasures.

Selection of countermeasures depends on the series of criteria, including the result of stability analysis, landslide scale, affective by a landslide to local people and infrastructure (spatial relation to a road), and budget. However, because of having no the workflow of strategies for the selection of maintenance and management methods of mitigation and prevention of landslides, engineers and management agencies do not know when and which solution will be effective.

3.5 Conclusion

Landslides phenomenon occurred along roads are considered a natural disaster directly affected the development of local areas and the transportation sector in particular.

Although the Vietnam government has overall strategies to deal with natural disasters like a landslide the results of response, mitigation and prevention of landslides are still limited. The root causes are lack of experts with deep experience in landslide field, technological processes, guidelines for the survey, the design of landslide prevention are still in the process of building, finishing. In addition, have not been established a workflow of strategies for the selection of maintenance and management methods of mitigation and prevention of landslides, it can help engineers know how to choose an effective solution, and management agencies easier making a decision.

Hence, besides continuously updating and supplementing a wide range of finishing manuals on survey and design of previously described to keep up with advanced scientific technology all over the world, it is necessary to build up a strategy for the selection of maintenance and management methods of mitigation and prevention of landslides, which compatible with humid tropical zones such as Vietnam.

CHAPTER 4. THE DETAIL OF ITEMS FOR TOTAL MANAGEMENT OF LANDSLIDE DISASTER RISK

4.1 The framework of the total management flow for landslide risk.

Landslide being a dangerous natural disaster, unexpected and destructive catastrophe, especially in mountainous areas. This type of disaster has caused great losses, which is one of the reasons for pulling back the socioeconomic development of the mountainous provinces, especially causing panic among the local people. For mitigation and prevention landslide disasters, Vietnam Government has also developed the strategy and vision at the macro level. Beside, a series of programs and projects aim to support the local governments and local resident live in the high risk of landslide zones were performed such as landslide risk mappings, flash flood - debris risk maps for whole of Vietnam's territory (the scale 1:3.000.000 and 1:1.000.000), and map for three key areas in the northern mountains (scale 1:50.000), landslides distribution map's scale of 1:50.000 for 14 provinces in the northern mountains. But these maps are just supporting for macro planning design and strategy orient purposes. For micro applying, it is necessary development more detail maps, with a suitable scale, such as 1:25.000, 1:10.000 or smaller.

In addition, the application of the results of these maps for warning and guide to the resident preventing effect of landslide was not enforced or very embarrassing. Landslide phenomenon occurs frequency annual caused damage people and property, while the local governments and resident face to disasters are seem completely passive. This is due to the lack of scientific data reliable enough to predict and warnings to people. The behavior with landslides remains under the specific landslide occurs. Besides, the treatment solution has not been compatible or not, thoroughly lead to the landslide continues to recur and the countermeasure works continue to fail. That is to say, actually there is poor advancing or the improvement of landslide management technology yet (Dung et al, 2016).

Landslide risk assessment technology as well as the research and application of early warning for mitigation and prevention of landslides in Japan recently have made great advances. In addition to having sufficient resources for research, they have a reasonable comprehensive total management flow of landslide disaster risks, which is bringing the effective indeed. For example, Fig. 4.1 is the countermeasure of disaster occurrence current Flowchart for landslide investigation in Japan.

This study likes to propose a framework of total management for landslide disaster prevention, mitigation and the control suitable for Vietnam. It starts from the data collection, landslide topography mapping, field investigations, soil strength evaluation, susceptibility mapping and reactivation risk evaluation, risky site prediction, risk evaluation in site, monitoring and countermeasure.

For this purpose, we have been carrying the series of programs, i.e. identify the landslide area by aerial photo interpretation and ALOS W3D data contour analyze, wider area mapping, field investigations, soil strength evaluation, susceptibility and reactivation risk evaluation, monitoring by field check and UAV/SfM processing, identify the geological structure and identify the slip surface etc. The trial covers almost of all areas of landslide management in the field. The landslide topographic area identification and the mapping, landslide mechanism analysis, safety factor calculation of a number of landslide disasters are carried along the HCMR, NH6 and NH7. This trial is the combined work of the using ALOS W3D data, field investigation, in site topography measurement, soil testing and simulation by Ad-Calc 3D. The landslide distribution map is established along the NH7 is completed based on the ALOS W3D data and more than 1000 landslide areas are identified (Dung et al, 2016).

The combination works with contour from W3D data, field investigation data and simulation lead us the presence of real phenomena and will suggests the alternative countermeasure strategy setting up. Fig. 4.3 is the propose framework of landslide investigation and the management for landslide disaster prevention, mitigation and the control. It will be mentioned in the Chapter 5.

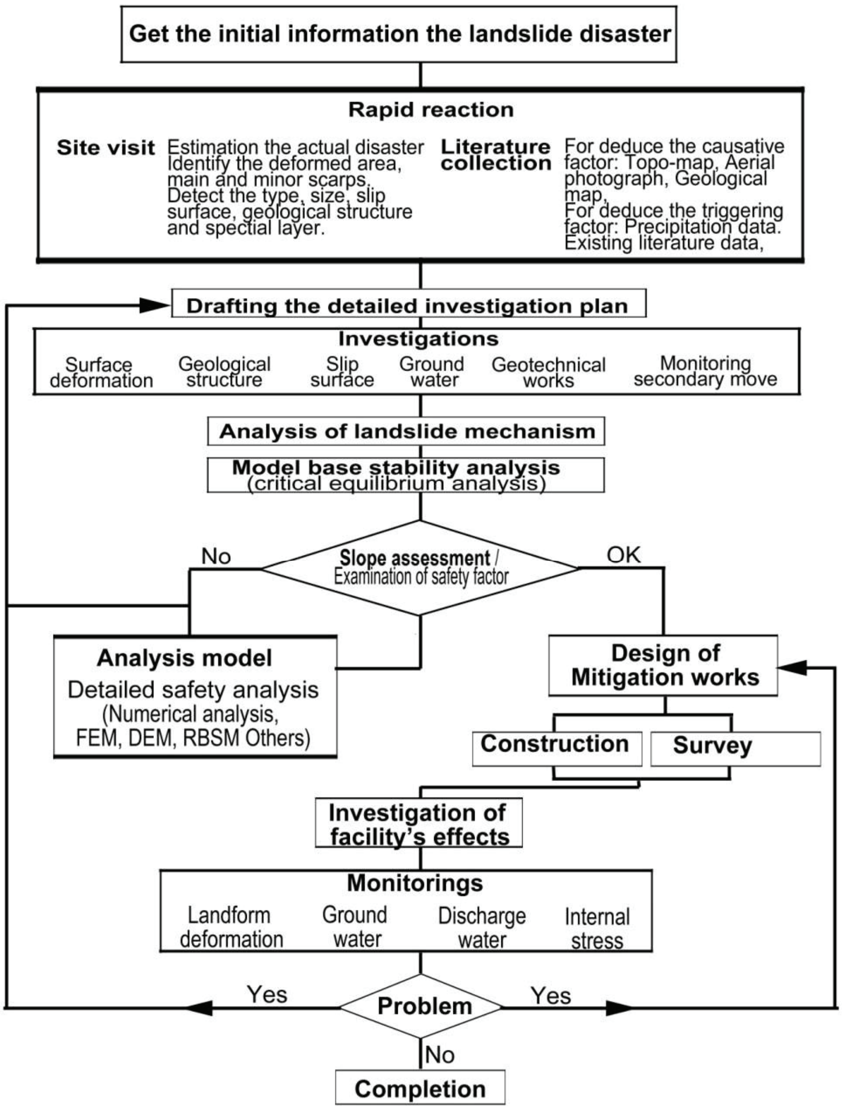


Fig.4. 1 Countermeasure of disaster occurrence current Flowchart for landslide investigation in Japan

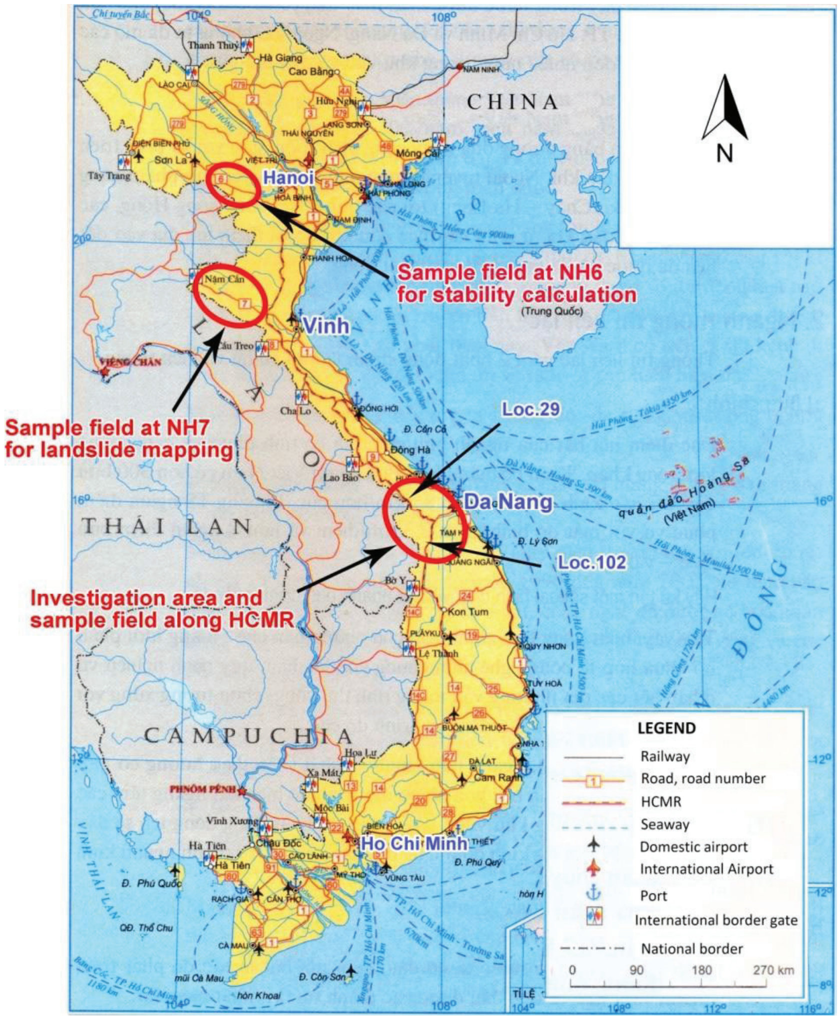


Fig.4. 2 Locations map for this study.

4.2 Landslide susceptibility mapping and landslide topographic area mapping.

4.2.1 Summarize the current risky site mapping.

Landslides, being natural disasters, are considered threats to life and financial capital. Research on landslides has been employed in the fields of science and technology development that relate to natural disaster prevention. That is to say, it has become applied science that is: 'utilized when landslides unfold and natural disaster occur'. Recent projects on 'understanding the host of risks linked to landslides' or 'risk evaluations of landslide topographies' in Japan's academic community focusing on landslides has made great advances; moving from past counter measures towards forecasting inference of landslide risks. We have promoted and contributed to these developments. Thus, this study builds on these advances and reflects chronologically on how 'technology aiming to understand existing risks of landslides' has been constructed and linked to the risk evaluation, and discusses the significance of mapping landslide phenomena. Just recently, the susceptibility of landslide disasters has been discussed by Tien et al (2016). The large scale landslide topography mapping and the inventory used aerial photographs has been discussed by Le et al (2016).

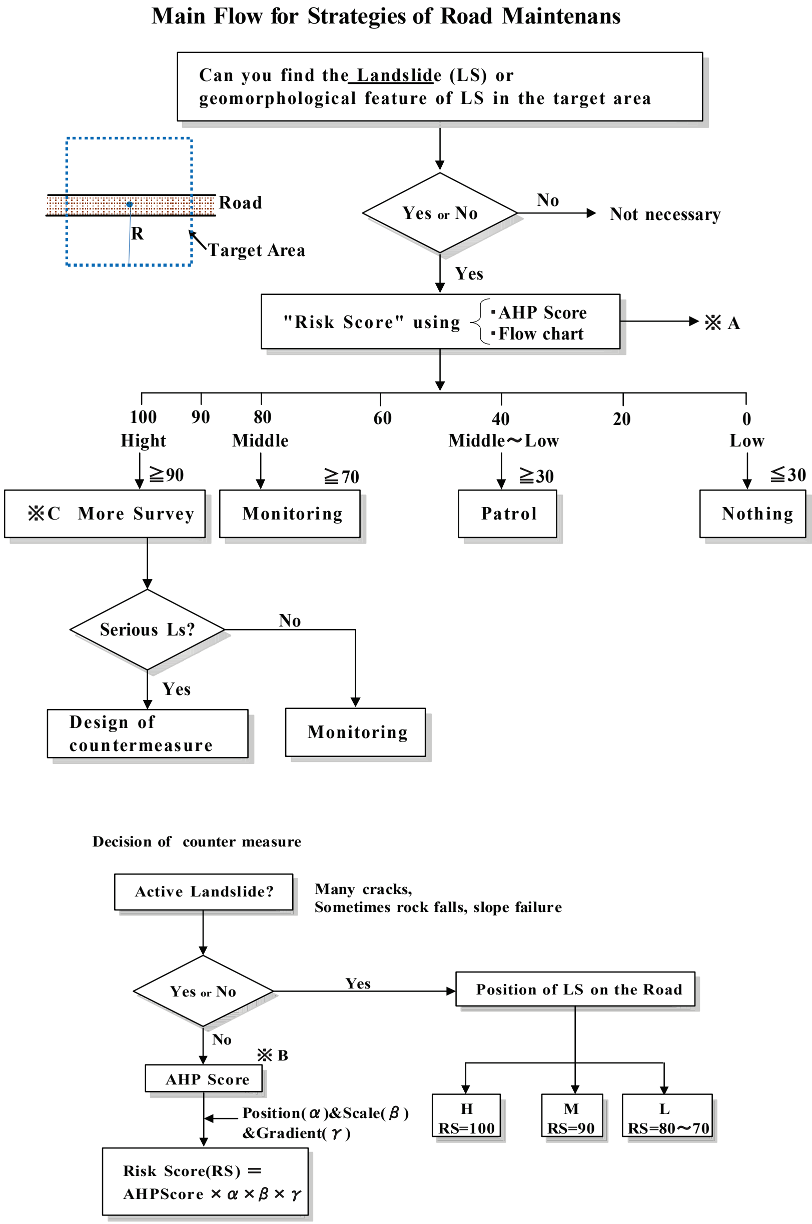


Fig.4. 3 Mail flow of landslide management (above) and sub flow (below) along the roads (Dung et al. 2016)

According to the study results of the landslide susceptibility map of the study area along corridor HCMR from Quang Tri to Kontum and with the division of the landslide index of Galang Method applied, the Galang Method was introduced from 2004, with landslide susceptibility divided into four classes from low to very high landslide sensitivity. The number of landslides 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. 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 (Tien et al., 2016).

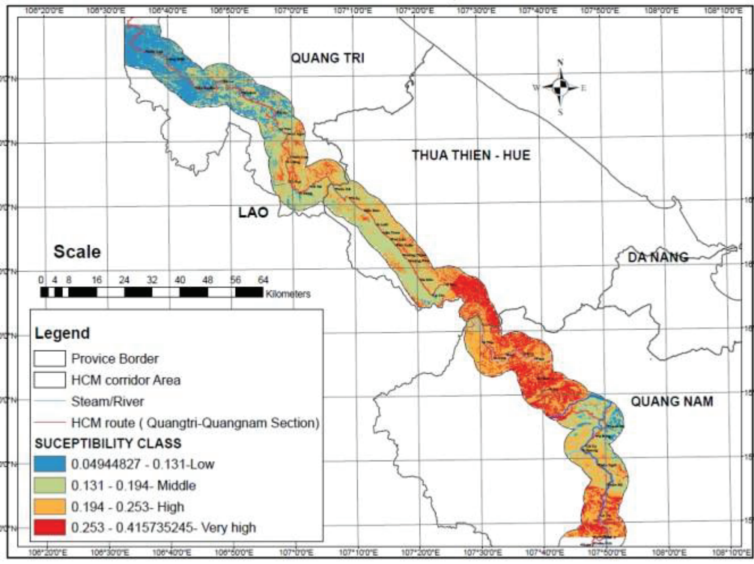


Fig.4. 4 Landslide susceptibility map of the study area, along HCM route from QuangTri to Kontum.

The large scale landslide topography mapping and the inventory have been made for the area along corridor HCM route between Prao and Kham Duc. The inventory was prepared by interpretation landslide observed on over 100 aerial photographs at a scale of 1:33,500 that were taken in 1999. They used these photographs because, at the time of this study, only 1999s aerial photographs are available. Interpretation of aerial photographs was locally aided by field checks. By this way, all the unstable areas were mapped at a scale of 1:25000 onto topographical maps. The map was transferred to GIS and contains on 685 landslides, corresponding to an average density of 0.6 landslides per square kilometer. Landslides range in size from 3071 m2 to 3.08 km2, and the most frequent (abundant) landslide has an area of about 25,400 m2. They classified into five categories. 324 of which are classified as rotational slide, 66 are classified as translational slide, 4 are classified as compound slide, 275 are classified as debris slide and, 16 are classified as debris flow. For each landslide, 13 characteristics were recorded and listed in the accompanying database table. Combine with geological map, among 685 landslides were mapped, 314 landslide topographies belong to Mesozoic; 178 landslide units belong to Paleozoic; 171 landslide units belong to Precambrian; 22 landslide units belong to Quaternary. Most of landslides occur in Mesozoic zone, occupy 46% of recorded landslides (Le et al., 2016).

The maps show interesting distribution features: 1) the spatial distribution seems to have some relation with geological periods. The large-scale landslide topography concentrates in the area of the Mesozoic geology. The Paleozoic geology has few large-scale landslides except in areas of plutonic rocks such as Gabbro and granitic rocks. Especially, the largest landslide topography is located at the Gabbro. The Quaternary and Precambrian geology also has several characteristics. The movement features are categorized into five types: Rotational slide, Translational slide, Compound slide, Debris slide, and Debris flow (Le et al., 2016).

On the other hand, an interesting characteristic observing at the part of northward homo-clinal slope at a southern part of major Mesozoic Syncline. A big number of landslides and scars are distributed, and there are very remarkable topographic features identified, the scars are distributed at the northward dip slope, on the contrary, many types of landslide topographies locate to another direction of slope the size of landslides is relative of small but it easy to identify in size, and such landslides and scars distribution are strongly reflected the geological structure. It means in case of landslide distribution and the type in the case of the Mesozoic sedimentary rock controls the characteristics (Le et al., 2014).

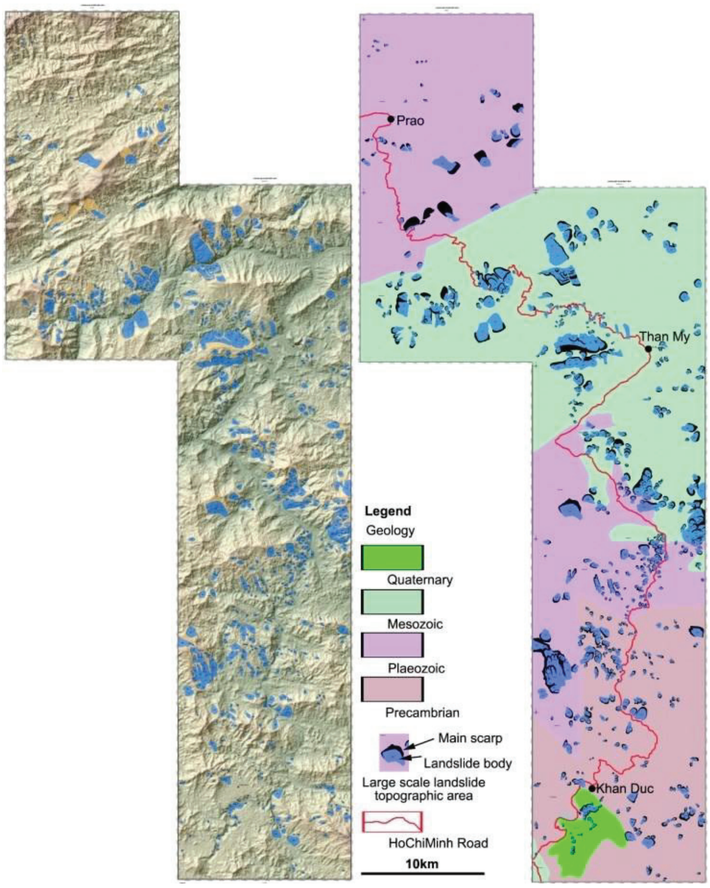


Fig.4. 5 Maps of landslide topographic area from Prao to Kham Duc along the HCMR, central Vietnam (Le et al., 2016).

4.2.2 Landslide topography mapping using AW3D data and field investigation

4.2.2.1 Landslide topography mapping along the NH7 using ALOS W3D data

In order to reduce the landslide disaster which occurs in the area along the artery such as national roads, it is important to clarify the distribution of landslide topographic features. However, is too small, or the accuracy of a topographical map is not sometimes necessarily suitable. Moreover, when taking an aerial photo newly, very big cost may start. There are never many countries which an aerial photo is taken repeatedly and it can purchase freely and cheaply at a rate once in ten years like Japan.

From 2015, based on the picture of millions of sheets which ALOS photoed, 5 m mesh DSM (ALOS W3Ddata) and ortho data in the world are fixed, and it can purchase now. Then, for the NH7 of central Vietnam, the contour line was created from the DSM data and the topographical map was created. We decided to find out landslide topographic features by deciphering the contour line of this topographical map. As a result, 1000 or more landslide topographic features were able to be checked. It will be evaluated what kind of potential disaster vulnerability this landslide feature will have from now on.

This study presents an investigation of the distribution of landslide topography over the area along NH7, which runs from Vinh city located at the northernmost end in central Vietnam to the Laos border via Nghe An Province. The novelty of this study is that analyses have been conducted based on digital surface model (DSM) data (W3D data) of a 5 m grid, with orthographic images created from image data acquired from ALOS. This strategy was undertaken because of huge costs and effort necessary for newly acquiring aerial photographs. Accordingly, an objective of this study is an evaluation of the validity of using these DSM data for the mapping of landslide topography.

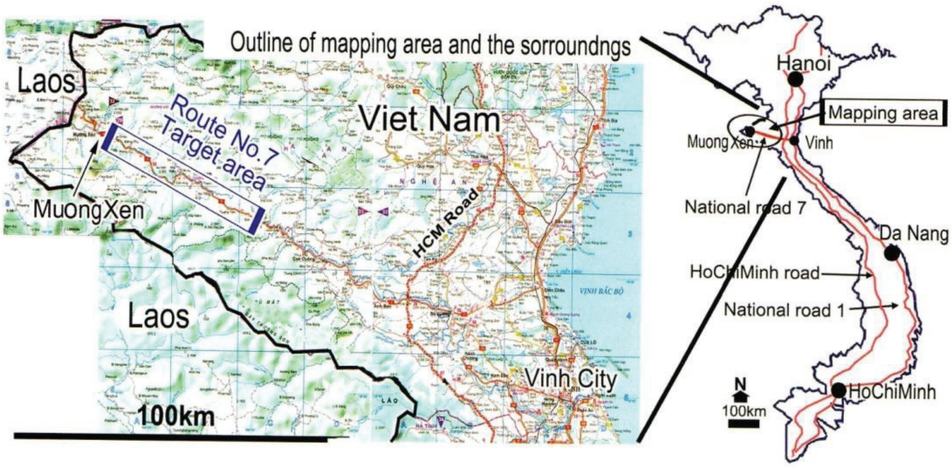


Fig.4. 6 Location maps of the study area.

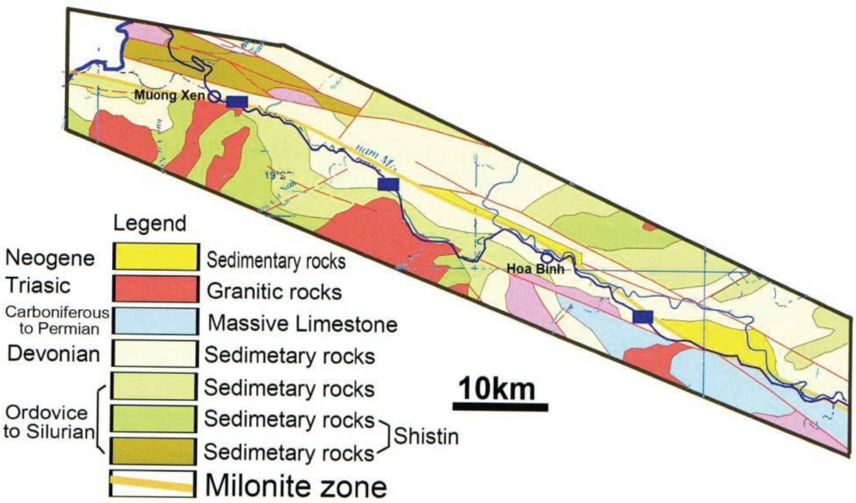


Fig.4. 7 Compiled geological map along the NH7

(1) The landform characteristics along NH7

Outline of the Target area

In humid tropical zones such as Vietnam, slopes are exposed to various destabilizing factors, which are represented by deep weathering exacerbated by heat and high humidity, with erosion by heavy rains and river bank erosion caused by unexpected increases in the flow rate. Furthermore, the geology of the whole area has been affected by severe diastrophism since the Paleozoic era. Such regional peculiarities, with the mountain range, especially close to Laos, typify this region of frequent landslides. NH7, a lifeline network of about 200 km extending from Vinh city to the west–northwest Laotian border, is a traffic artery connecting Laos and Vietnam. Located at the mouth of the Ca River, Vinh city, the origin of the route, is a large peripheral city of about 500,000 populations. NH7 runs along this river. Hills and mountains spread about 80 km upstream from the origin. On the way, it crosses the HCMR extending north and south of Anh Son town. Then a steep mountain range extends upstream from Hoa Binh. The Ca River, which flows along a major tectonic line of the Paleozoic, is very straight in perspective. The geology constituting the mountain range is occupied mainly by sedimentary rocks of the Mesozoic to the Paleozoic, although limestone of the Mesozoic is broadly exposed in eastern areas, forming the landscape of tropical tower karst. Another characteristic of this region is a great tectonic line regarded as playing a major role in the geologic structural formation of the Paleozoic. The Ca River watercourse mostly follows this tectonic line. Furthermore, a great tectonic line (metamorphic belt) called the mylonite zone exists on the mountain slope by the side of the left bank, where slopes form cliffs. Although landslides are apparently observed more on the western part (inland side), the distribution remains unclear.

Topographic configuration of the Target area

A topography classification chart particularly addressing the shape description of landslides was prepared to width of about 1 km on both sides of NH7 in central Vietnam as the centerline. The topography of this region is mostly mountainous slope areas of the Mesozoic and Paleozoic. This slope region was classified into landslide topography, crest slopes, valley side slopes, and tropical tower karst. The landslide topography often reflects the so-called embedded structure in which large-scale landslide topography is subdivided by landslides of a smaller scale. In such a case, this grouped structure is denoted as the landslide complex. The minimum division of a physiographically grouped landslide is expressed as the landslide unit. Observed geomorphic surfaces include several steps of river terraces developing along the watercourse of the Ca River and alluvial cones by earth flow scattered at the bottom end of the mountain stream. The characteristics of each landform classification unit are presented below.

Landslide topography: A landslide is a phenomenon by which a part of a slope moves along a slip surface. A topographical region produced by this action is designated as landslide topography. Accordingly, it is distinguishable by a level difference and a break line between a sliding zone and a non-sliding zone. A landslide comprises a main scarp, a landslide body, and a slip surface. Details of the characteristics of this landslide topography were described by Vearns (1985), Miyagi et al. (2004), and the Landslide teaching tool (2013). The micro landform of a main scarp and a landslide body was read from contour lines of an interval of 5 m. The previously described embedded structure was expressed so that each landslide unit was distinguishable to the greatest extent possible.

Crest slope: It is located in the topmost of the longitudinal and cross sections of a slope. Its section is often convex. Its soil is usually thin regolith, presenting so-called reddish weathering in this region, where a thick weathered layer formed in a geologic time scale was denuded by turns.

Valley side slope: It is a slope located between the bottom of a valley and the crest slope, most of which has become steeper because of surface failure. Frequent rock exposure is observed because of thin soil, but the exposed rock itself might comprise a reddish weathering formation.

Terrace surface group: Several steps of river terraces have developed along the Ca River watercourse. Its lower level is 10–20 m above the riverbed, and is intermittently observed at both banks of the river. Major villages such as Muong Xen and Hoa Binh occur on this lower level. A river terrace plane group with a rounded gravel bed has an approximate thickness of 1–5 m, at a height about 20–50 m above the lower level from the river bed. This sediment is fine gravel – boulders. The matrix is weathered reddish argillaceous loam. This terrace sediment is observed to have greatly crept at the part contacting slopes like a river bank, suggesting that even terrace sediment formed on and after the middle of the Quaternary has become cohesive soil by a severe chemical weathering process, and suggesting that further mass transfer is sufficiently active to creep.

Alluvial cone: Several small-scale fan-shaped alluvial cones are present in the survey area. An alluvial cone is a topographical feature formed when frequent occurrence of surface failures stimulates the accumulation of extensive earth and sand in a mountain stream, becoming mudflow in a mountain stream.

Tropical tower karst: This corrosion topographical feature is formed of limestone of the Mesozoic distributed over the eastern part of the survey area. Landslide occurrence is not so prominent.

Fig.4. 8 River terrace deposits and its creep features, base rock characteristics: 1) Near Prao town. River terrace deposit clearly creeping at the river side slope. 2) Thin river terrace deposit and creep along the Ca River. 3) Creep phenomena, deep reddish weathering phenomena at the location of photo 2.

(2) Landslide topography mapping by ALOS W3D data

The ALOS World 3D Topographic Data

The Advanced Land Observing Satellite "DAICHI" (ALOS) launched by Japan (JAXA) has captured 3 million Earth images. Three organizations, Nippon Tele-communication Technology Data Corporation (NTT Data), The Remote Sensing Technology Center of Japan (RESTEC) and JAXA, conducted processing for these images jointly, and built up digital information of a 5-m mesh and orthographic images that cover the entire world. However, these 3D data are not perfect because they are DSM data: to the degree that they are DSM, they are not representative of information acquired by direct measurement of the topography. Because they are originally created from ALOS images, nothing can be done but inferring the tree height of the region and subtracting it from *Z* (height) value to generate a Digital Elevation Model (DEM). However, image information covered by vegetation is obtained by reading recognition from aerial photographic interpretation conventionally, so that it is presumably possible to attain the same accomplishment from DSM as the topographical analysis by interpretation of aerial photographs. Although aerial photographic interpretation is ordinarily the first step in creating distribution data of landslide topography, it is difficult to undertake aerial photography in many regions. Therefore, it is assumed to be possible for such regions that landslide topography is recognizable by interpretation from a contour line distribution pattern by preparing suitable contour map information using data of a 5-m mesh as was done for this study. The 5 m and 10 m contour maps created for interpretation this case.

In this mountain range, as in most of Vietnam, many landslides are visible. Aerial photographs taken in this mountain range are "mostly of a scale of 1:33,000, and have been taken only once in the past." The stereoptical interpretation of images of a scale of 1:30,000 would provide nothing more than a basic image of the outline of landslide topography. NIED of Japan has usually used aerial photographs of a scale of 1:40,000 in the Landslide Distribution Maps project, in which the minimum scale of landslide topography extracted by aerial photographic interpretation is specified as width of about 100 m (Oyagi et al., 2014). Moreover, the landslide reactivation risk evaluation is based on a micro-landform interpretation using aerial photographs of a scale of about 1:10,000. According to Luong et al. (2016), it is difficult to evaluate a micro landform with aerial photography of a scale of about 1:30,000. However taking aerial photographs again by airplane requires huge expenses. Such circumstances are common in many states worldwide, as well as in Vietnam. Therefore, it is regarded as meaningful to examine the possibility of analysis using W3D data in various regions in the world. Five ground m corresponds to 0.15 millimeter on the contact printing of an aerial photograph of a scale of 1:33,000, so that the precision of W3D data of a 5-m mesh is almost equivalent to that of aerial photographs that are actually used in Vietnam. Consequently, it is natural to infer that an accomplishment equivalent to landslide topography distribution data based on aerial photograph interpretation can be acquired from W3D data using a topographic map with an appropriate contour interval. It is also considered possible to obtain finer relief information by selecting an appropriate interval of contour lines.

Landslide Topography Mapping by W3D Data

It is not necessarily easy to comprehend the distribution of landslide topography in spite of the occurrence of landslide disasters worldwide. It is even more difficult to evaluate the reactivation possibility of each landslide. Luong et al. (2016) describe this situation. Here the validity of judgment as landslide topography by W3D data is verified in comparison with the judgment at the real site. Aerial photographic interpretation is compared with the landslide topography classification by W3D data at the Hai Van Mountains in central Vietnam, in which the validity assessment of landslide topography mapping using W3D data is also to be conducted. Fig 4.9 classifies landslide topography that can be read out in W3D data and related topography using a somewhat larger scale landslide topography as an example. The relation between "a main scarp and a landslide body", the principal element of landslide topography, can be comprehended quite distinctly, and a horseshoe-shaped micro landform can also be found, which is regarded as a small-scale landslide condition change generated in and out the landslide body. Moreover, it was possible to verify "How correctly small-scale landslide topography observable on site can be inferred from W3D data" with several small-scale landslides along the HCMR as objects. Fig 4.10 depicts a landslide with width of about 130 m that took place along a road as one example. Comparison between contour lines of a 5-m interval generated by W3D data and the actual landslide shape verified that the contour of a landslide can be roughly reproduced. However, important micro-landform boundaries were pointed out, such as a boundary between a cliff and a landslide body, which tended to be expressed more gently. This phenomenon often arises in processing grid data. Accordingly, results suggest that simulations such as three-dimensional stability analysis using these data might be conducted based on these data, but contour lines used for computation should be revised based on the observation result of the actual micro landform. Weak points of DSM were revealed: some places were unsuitable for aerial photographic interpretation, such as places thick with high trees or long continuous cliffs with dense contour lines at the boundary between cultivated land and thick forest. The processes directly related to this study are the following.

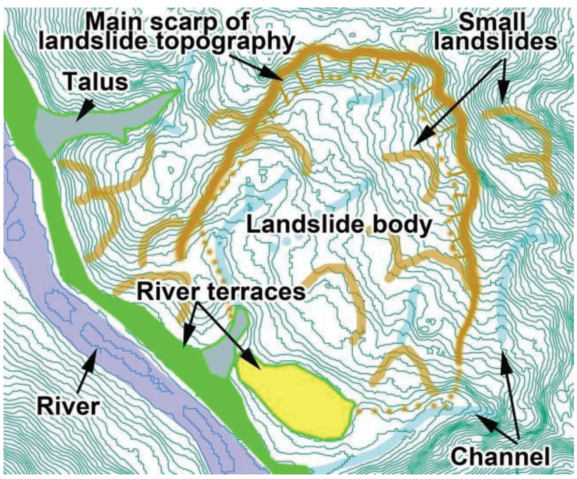


Fig.4. 9 Example of landslide and related topography identification. The 10 m contour interval map is established from ALOS W3D data.

First, contour lines of a 10-m interval were generated from W3D data. A topographic map of 1:20,000 was produced for about 12 km to the west of the area for mapping. This contour map suggests that a main scarp and a landslide body that constitute a landslide can be extracted for landslides of a scale of a width not less than 200 m. Accordingly, field survey results for three sites with distinct landslide condition change were compared with a landslide interpretation chart. Next, a topographic map of a 5- m contour was produced throughout the area for mapping. Because W3D data were originally of a 5- m grid, contour lines generated from the *Z* value were made to a 5- m interval. Results suggest that a small-scale landslide with width of about 50 m can be recognized.

Comprehension of actual Slope Movement Conditions

For this study, field surveys were administered in this region twice, in May 2014 and April–May 2015, while W3D data were introduced into the end of 2014. At three sites, remarkable topography condition changes were observed at a field survey. Local information around the sites (topography and geology, and characteristics of condition changes) and correspondence with landslide topographic information using W3D data were investigated in this study. The results are summarized as follows.

A landslide topography map produced from W3D Data was compared with the 1:200,000 geological map compiled and published by the Geological Survey of Vietnam. The distribution of landslide topography corresponds distinctly to geological conditions. The geology of the region subjected to interpretation contains meta sedimentary rock of the Paleozoic Ordovician to Silurian period, similar sedimentary rock of the Devonian to Carboniferous period, sedimentary rock accompanied by limestone in the first half of the Mesozoic, and granitic plutonic rocks. Furthermore, a large-scale tectonic line accompanied by mylonite extending east–southeast from west–northwest runs through this region. Cliffs extending to the east of Muong Xen, on the mainstream of the Ca River, reflect prosperity of the geological features along this tectonic line. Typical tropical tower karst is observed broadly in the eastern part of the area where limestone prevails, although there are many steep slopes and topography prone to landslides concentrated in the area from Hoa Binh to Muong Xen.

Especially, a region along the tectonic line where the Paleozoic is distributed is densely segregated by landslide topography. It is anticipated that a database of landslide topography distribution and the correspondence state of geological maps to it can clarify the relation between geological features and landslide occurrence. Three example relations are shown for clear landslide sites that displaced NH7, and a landslide topography classification chart. A landslide topography map containing LS 1 and LS 2 is presented in Fig. 4.11, on-site photography of LS 1 in Fig. 4.12, on-site photography of LS 2 in Fig. 4.13, and data of LS 3 in Fig. 4.14.

A part of the toe of the landslide body is located on the attack slope of the river in LS 1. This slope is as steep as about 30deg overall. The landslide lies severely breaking this slope whose main scarp and landslide body are distinctly visible. Part of the landslide body has been deformed because it was removed for use in macadam. Presumably, sandstone and mudstone that became schist of the Ordovis period formed a dip slope structure of about 40 deg; a slip surface was formed in a part thereof to cause the landslide. Photo 1 of Fig. 4.12 is a photograph of a stratum that constitutes the landslide body. Photo 2 is a photograph including the landslide body and the immovable object. Photo 3 is a close-up photograph of the slip surface.

LS 2 is a landslide 500 m away to the west from LS 1. This landslide is about 200 m wide. The toe of the landslide body was pressed out to the river. Its geology is almost identical to that of LS1. The national route is deviated to the river side by 2–3 m by the landslide body of this landslide. Although this displacement is repaired annually, the continuous movement is always peeling the pavement. Concrete stairs serve also as surface drainage. Grating crib works and retaining walls on the roadside slope are severely broken and

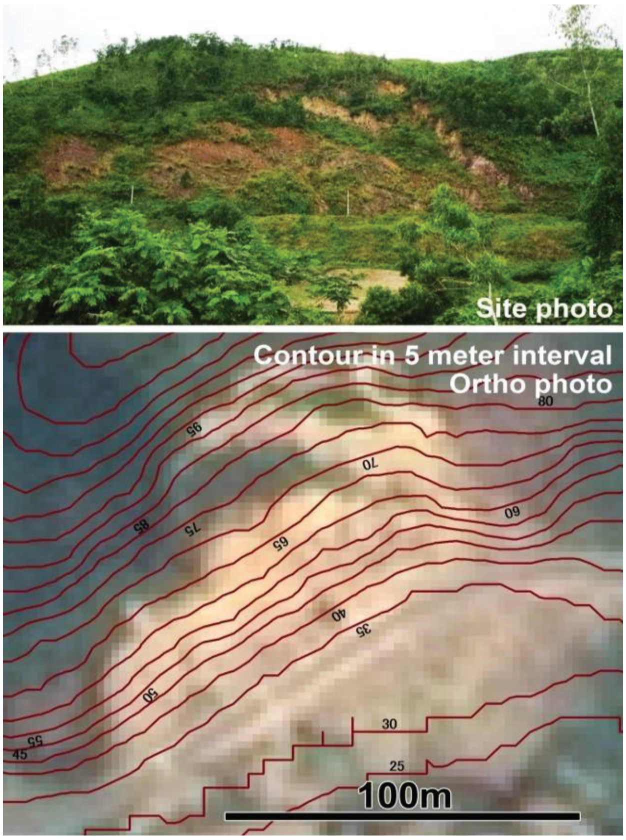


Fig.4. 10 Comparison between the actual landslide disaster, 5 m contour by ALOS W3D data and the orthographic image. The landslide is located near ThanhMy town near HCMR, central Vietnam.

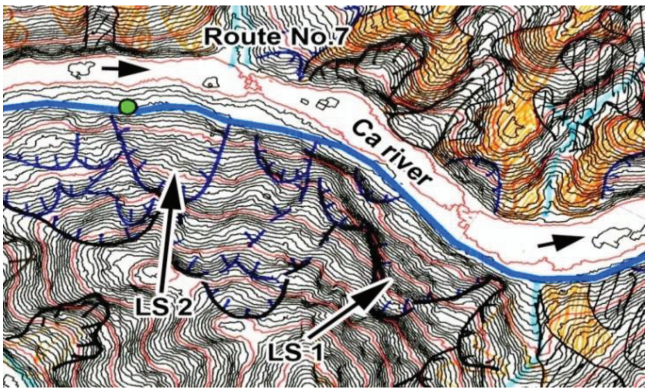


Fig.4. 11 Close up a part of landslide topography mapping area along the NH7. The location is mentioned in Fig. 4.

Fig.4. 12 Field photos at LS1. 1 in Fig. 4. , Steep and strongly sheared Paleozoic sedimentary rock. 2, A boundary of the landslide body and the slip surface. 3, Close up the boundary.

Fig.4. 13 Field photos at LS 2 in Fig. 4.: 1, The toe part of the landslide body deforms the road. 2, The body is pushing the retaining wall 3, The side boundary between the landslide body and non landslide slope.

deformed. Consequently, this landslide was verified as moving actively. Fig. 4.13 portrays the road surface deformation in Photo 1, fracture of the roadside slope in Photo 2, and the boundary between the landslide body and the immovable object in Photo 3.

LS 3 (Loc. 3) is located 6 km to the east of Muong Xen along NH7, where slope movement is observed clearly. The left half of Fig. 4.14 shows the landslide topography map: Photo 1 of Fig. 4.14 presents a full view of the landslide topography. Photo 2 shows the rock slide, exhibiting small scale but regarded as having moved for the first time. Characteristics of this landslide include formation of large-scale landslide topography facing the attack slope of the river, which was revealed by drawing a landslide topography map. It is also characteristic that the embedded structure of landslide topography is observed. About three stages of embedded structure are observed physiographically. Consequently, it is presumed as follows: fracture occurred in the whole region of Fig. 4.14, which made up a large-scale landslide topography, where landslides broke out as 1 of the classification map in the left panel, then blocks 2 were broken. Then they were subdivided into blocks 3, which are present today. Block 1 in the Fig includes all of 1, 2, and 3, and denotes the zone of this landslide travelling to the maximum scale. A field survey by the author and colleagues collected information that "A part of block unit 3 deforms the road surface" from community residents. The geology of the landslide body observed at a roadside slope shows severe fracturing, which is regarded as a result of repeated landslide deformation. Photo 2 shows a rock slide of a scale of tens of m wide: a small-scale landslide in which a landslide body facing the attack slope of the river forms a huge slab (base rock) and moves to fall into the river channel. This photograph presents the behavior of a huge slab of schist in which a schistosity plane slips down.

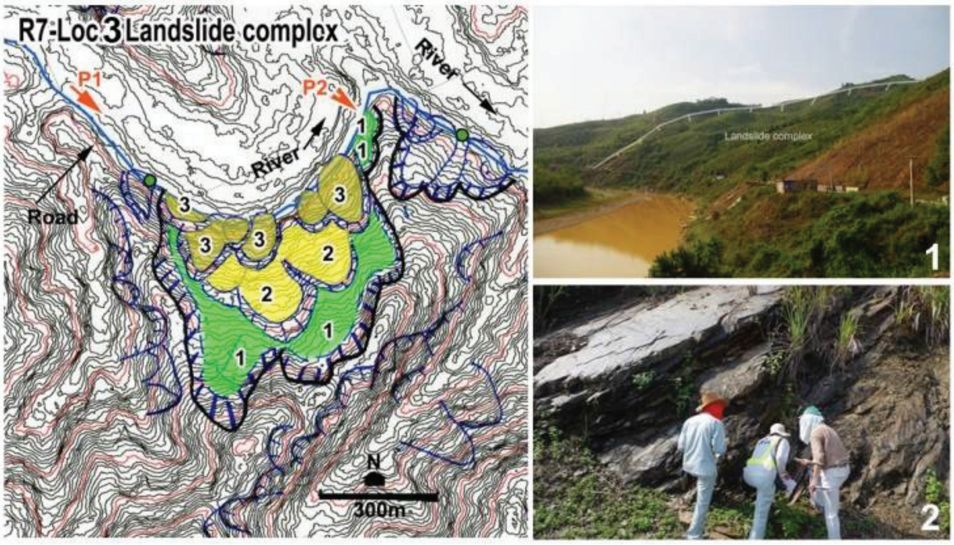


Fig.4. 14 Close-up a part of landslide topography mapping. 1; Over view the landslide complex. 2; Close up the rock and the structure at the lower margin of the complex.

(3) Conclusion – Landslide Topography Mapping by ALOS W3D data

A topographic map of about 10 km wide and about 70 km long centering on NH7 was created using this computed topographic map using the ALOS W3D Data, contour lines were read visually in a range of 3–4 km wide, centering on the national highway. Recognizable landslides were extracted and visualized. Fig. 4.15 shows a part thereof. Although only landslides of a width not less than about 100 m were extracted, the landslides extracted exceed 1,500. It is noteworthy that the embedded structure is also included. The identified area includes various types of slopes. The topography by fluvial processes such as those of terrace surfaces and alluvial cones, and non-sliding slopes such as those of ridge slopes and valley slopes, were classified and mapped together after proper judgment. These landform classification data will to be included in a database by GIS.

Results suggest that the distribution of landslide topography corresponds extremely well to the geography and geology. The distribution of landslide topography has high density in the western part (about 50 places within 10 km of road extension), and low in the east.

Furthermore, landslide topography is observed only slightly in the tropical tower karst region of limestone. Geologic phenomena corresponding to this are as follows: sandstone and mudstone deposited from the Ordovician to Silurian period in the first half of the Paleozoic were subsequently folded and metamorphosed to clay stone; the geological feature of steep slopes and development of numerous joint and fault structures was produced; and an extremely vulnerable geologic structure was produced by weathering peculiar to the tropical zone, such as generation of a weathered layer following emergence in the end of the Paleozoic, and red weathering advanced through the Quaternary. Development of dissection following formation of the drainage network of a river specified a slope scale and an average gradient. In the range for interpretation, the dissection in the western part is as deep as 500 m. Its slope is generally 30 deg or more, sometimes as much as 50 deg. Landslide fracture broke out on many slopes when such a steep and severely weathered rocks got a dip slope structure.

However, the relative height and gradient are reduced greatly, even on the identical geological conditions in the central part of the target area, so that the distribution density of landslide topography seems to show a great decline corresponding to this. Completion of the GIS database is expected to facilitate more accurate comprehension of such a distribution status.

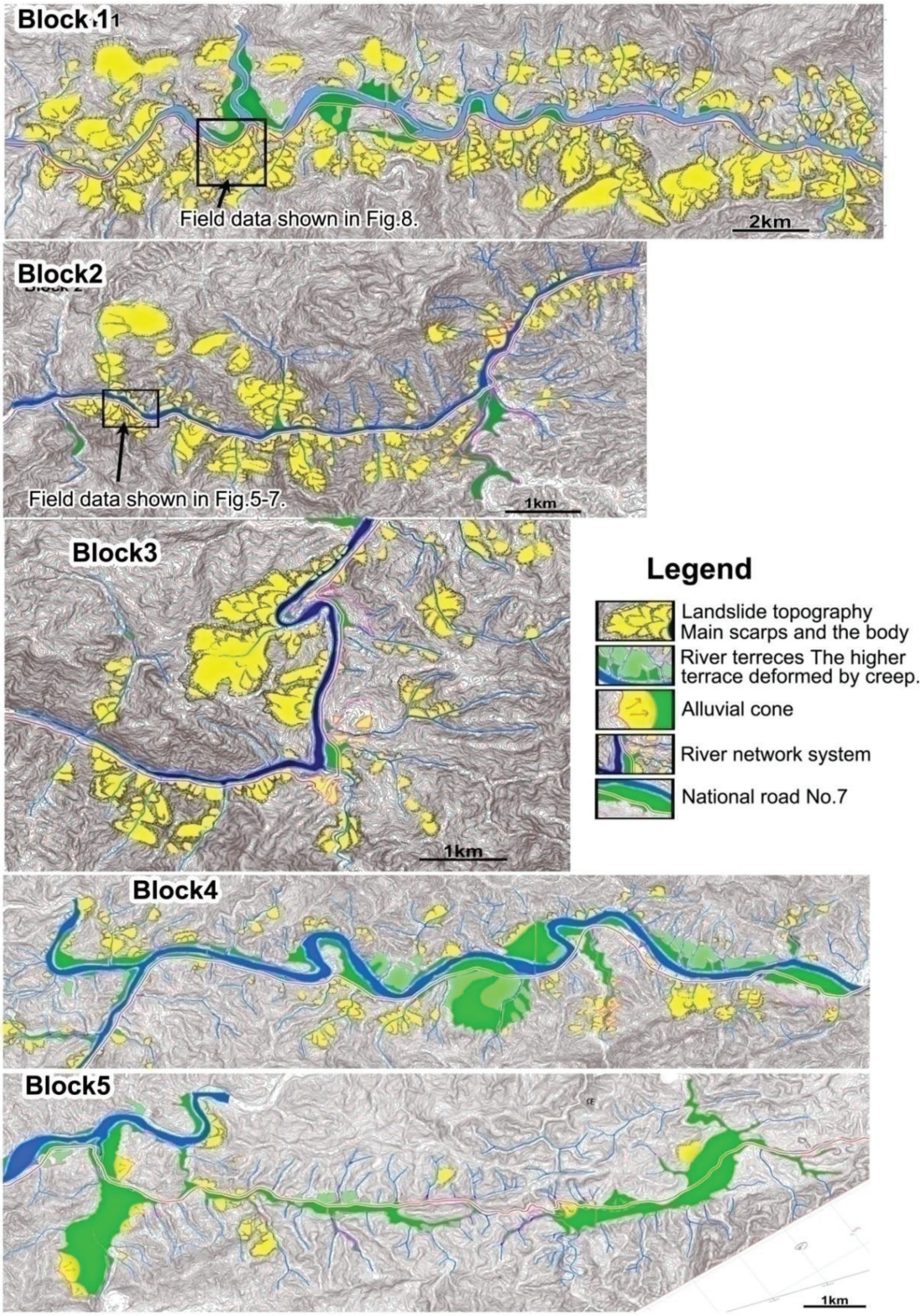


Fig.4. 15 The map of landslide topography area along the NH 7 betwwen Muong Xen (West end of Block 1) to Son Ha (East end of Block 5).

Quite recently, ALOS W3D Data used for creation of a topographic map and interpretation of landslide topography in this study were released. This study might therefore be the first to use these data for the preparation of a landslide topography distribution map of the world. Results demonstrate that information equally matched with verification by field survey can be prepared. The motivation for adopting these data was that taking aerial photographs in Vietnam was not necessarily easy. Newly taken aerial photographs require huge expenses that are expected to challenge any realistic research budget. In addition, aerial photographs of the mountain region taken in the past were of a scale of about 1:33,000, clarifying that they were unsuitable for the recognition of micro landforms from them.

4.2.2.2 The basic Data of Field Investigation for Landslides along Roads in humid Tropical region - Cases study at NH7 and HCMR in Central Vietnam

As discussed above, field investigation work should be taken in and after analysis of aerial photographs. This work will be very important to develop and clarify the results from analysis of aerial photographs. From 2011 to 2016, a series of field investigations were conducted along the corridor of HCMR and the NH7. During field investigation, slip surface, geological features, geology and weathering, type of landslides along the road have been discussed and clarified.

(1) The basic Data along HCMR

Ho Chi Minh National Highway is an important complementary for the existing trans-Vietnam road network, it shares the capacity for NH1. The total length of Ho Chi Minh highway is 3,300km but there are about 1,540 potential landslides along 2,200km road, with total lengths of landslides are 130km. It has caused serious environmental impacts through its negative effects to the forest corridor of the middle of the Truong Son Mountain (ITST, 2011).

A series of field investigations were conducted by ITST from 2006 to 2010, concentrated in a section from the Dak Rong bridge (intersection with NH9, connecting Dong Ha of Quang Tri to Lao Bao border gate with Laos) to Kham Duc (Kon Tum), about 350 km length. There were 548 locations of landslide occurred in this area. Classified followed Standard TCVN 9861:2013, the most common is Collapsed occupy 55.47%, next is Landslide occupy 32.12%, Erosions and Flows is 12.04%, and occurred rarely is Rockfalls only 0.37% (ITST, 2011).

In section from A Luoi to Thanh My about 150km length, the geological features of the northern part is mainly made up from sedimentary rocks such as mudstone, siltstone, sandstone, conglomerate, limestone, marl and shale from the Paleozoic era, metamorphic rock consisting largely of quartz schist and mica schist from the Paleozoic era, as well as granite. The distribution of these shows a tendency for arrangement in a northwest-southeasterly direction parallel to HCMR. Paleozoic and Mesozoic granite is widespread across the study area as a whole, and metamorphic rock which becomes hard Hornfels can be found in this area (Abe et al., 2014).

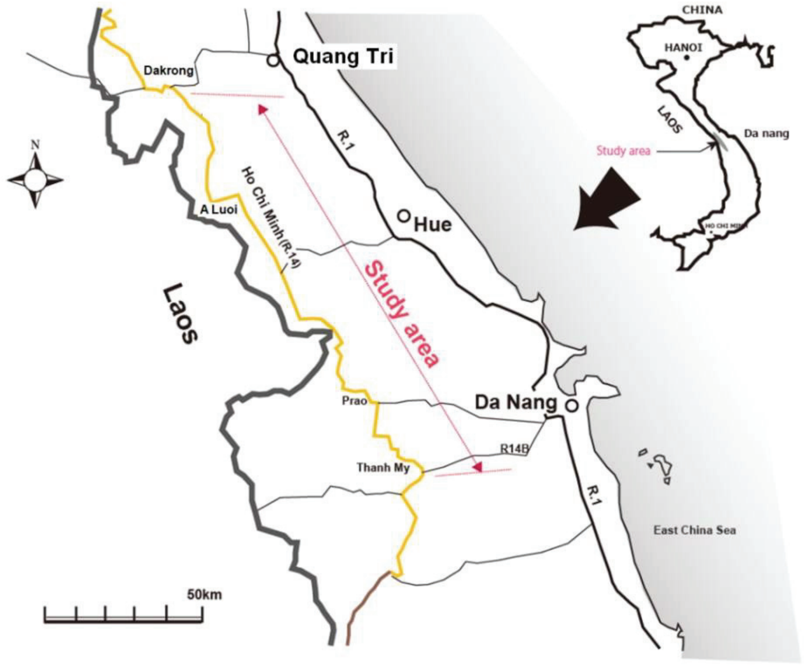


Fig.4. 16 Study area map

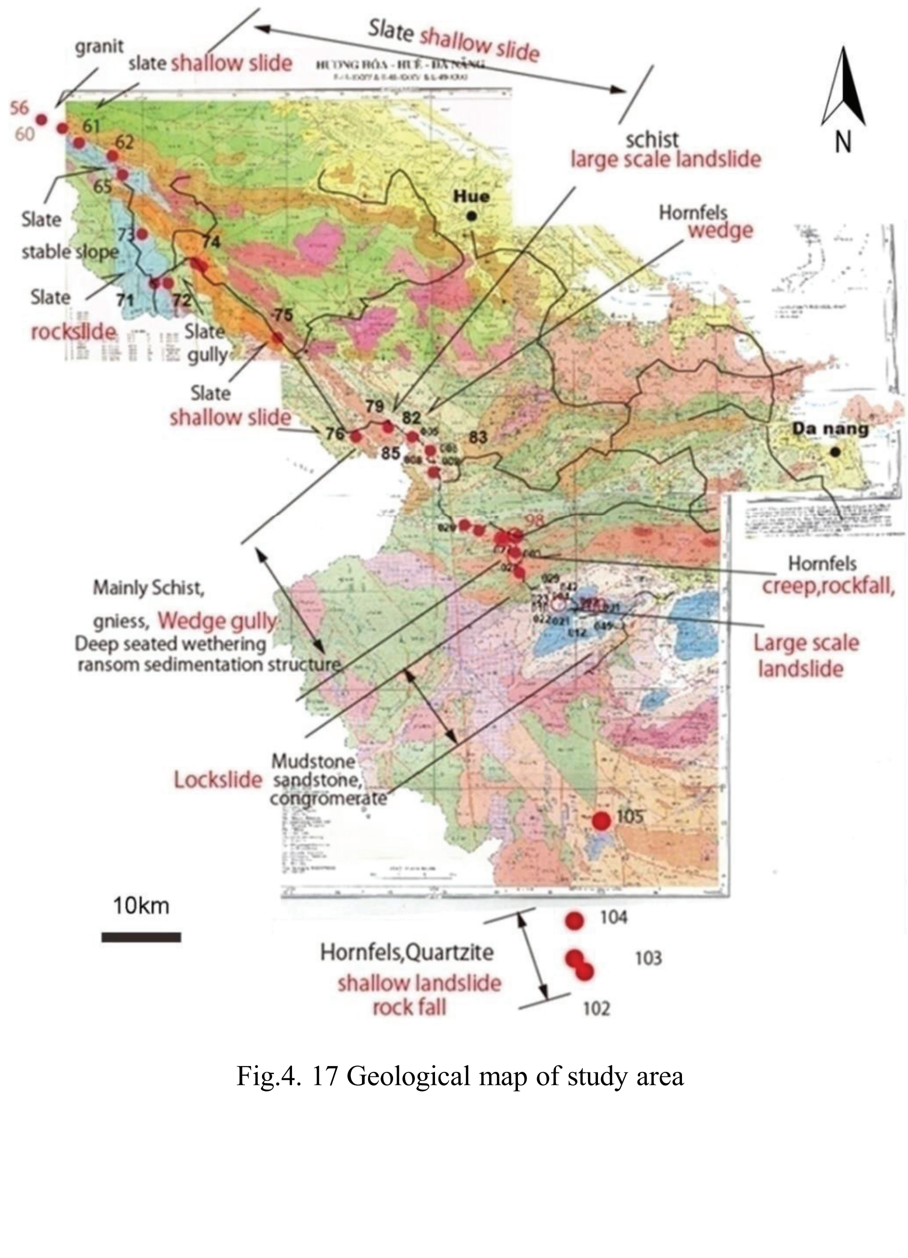


Fig.4. 17 Geological map of study area

Field investigated 182 locations of the landslide from A Luoi to Thanh My area from 2012 to 2014, Abe et al. (2014) divided into 6 types of landslide based on the classification of Varnes (1978) for landslide movement types. In addition to the classifications of translational rock slide, rotational slide, and rock fall, three landslide classifications were added such as translational wedge type slide where a moving mass slides in a triangular form, translational shallow debris slide where debris of thickness under 1 m slide down the bedrock, and gully type slide and flow where an arc-shaped sliding mass originating at the upper area of a slope slide down the slope surface, and the morphology resembles an erosion gully (Fig.4.18, Fig.4.19, 4.20). Therein, 40% of landslides in the areas of schist is the classification of gully type slide and flows, translational rock slides occupy approximately 70% of landslides in the area of Mesozoic sedimentary rocks. Rotational slide and translational shallow debris slide are common in the area of Paleozoic shale and sedimentary rocks. Gully type slide and flow are next commons. Approximately 60% of landslides in the area of hornfels distribution are rock fall. Granite/gneiss has a small distribution and has few examples of landslides, but various types of landslides occur including translational wedge type slide.

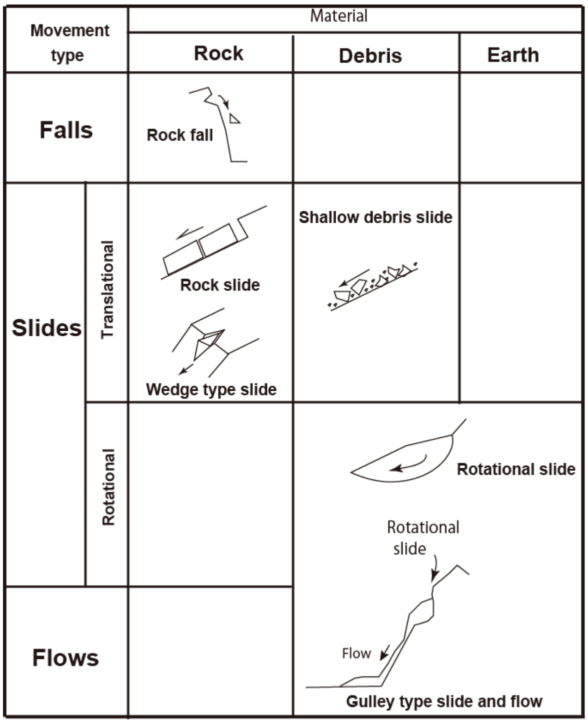


Fig.4. 18 Moving types of landslides along HCMR (Abe et al., 2014)

In the other section of HCMR, from Thanh My to Kham Duc have more than 30 ancient and active landslides were recorded. This area appears the surface landslides, shallow landslides and sometimes are deep landslides. The wedge type of landslides was combined by the geological structure and weathering structure. Surface landslides and shallow landslides usually are small sizes of landslides, but the number is much more. Sometimes, some small of landslides combined together to bigger landslide. An important feature is surface landslides and shallow landslides mostly distribution along the road, that were difficult recognition from aerial photographic interpretation, but emergency and dangerous, therefore it is a problem to control and mitigate it (Fig 4.22).

The Kham Duc town belongs to the Quaternary zone, geological structures are usually flat. Geological including lake deposits with extremely weak layers such as organic rich, peat

Fig.4. 19 Moving types of landslides along HCMR (No74: Translational shallow debris slide, No.10: Translational rock slide, No8: Rotational slide, No.79: Translational wedge type slide, No.72: Gulley type slide and flow) (Abe et al., 2014)

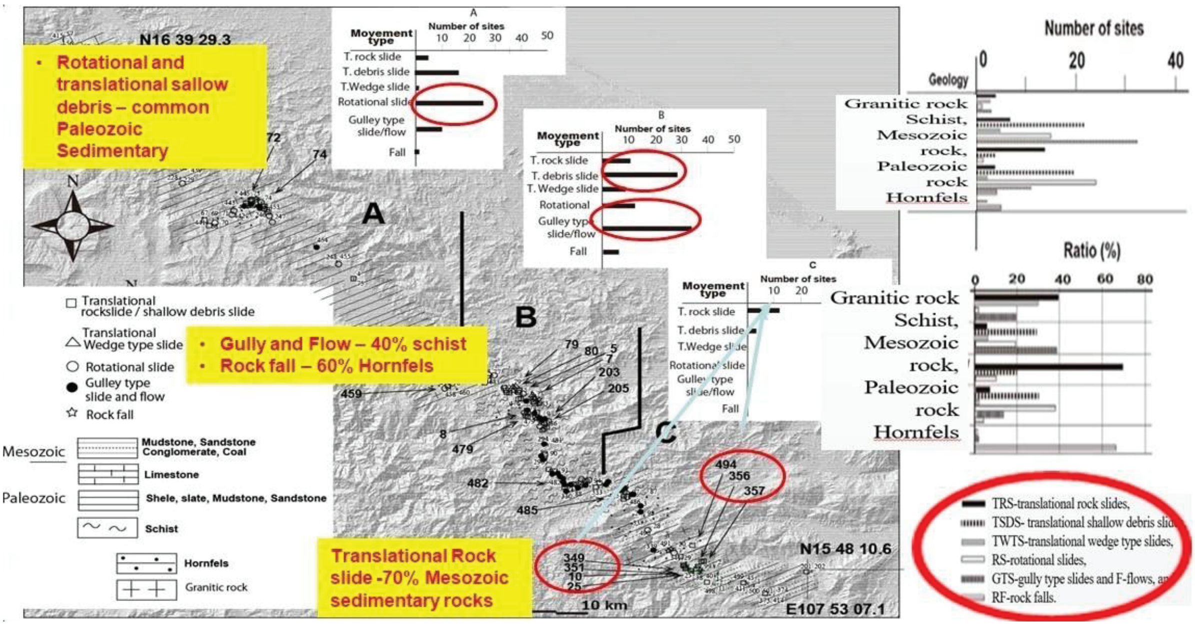


Fig.4. 20 Moving types of landslides and geology along HCMR (Abe et al., 2014)

and clayey layers, volcanic rocks with intruded basalt consolidate hard and heavy rock. The lake deposits are black, reddish brown, but the weathering level is not so deep. The boundary of the volcano and lake deposits is black deeply weathered material, with many holes because of the lava gas. Lake sediments are deeply weathered and changed in clayey materials (Fig. 4.23 & 4.24). Landslides occur as rotational slides along river side slopes, with a complex of small to surface landslides and soil creeps. Category and geological characteristics of landslides along HCMR from Prao to Kham Duc showed in Tab. 4.1.

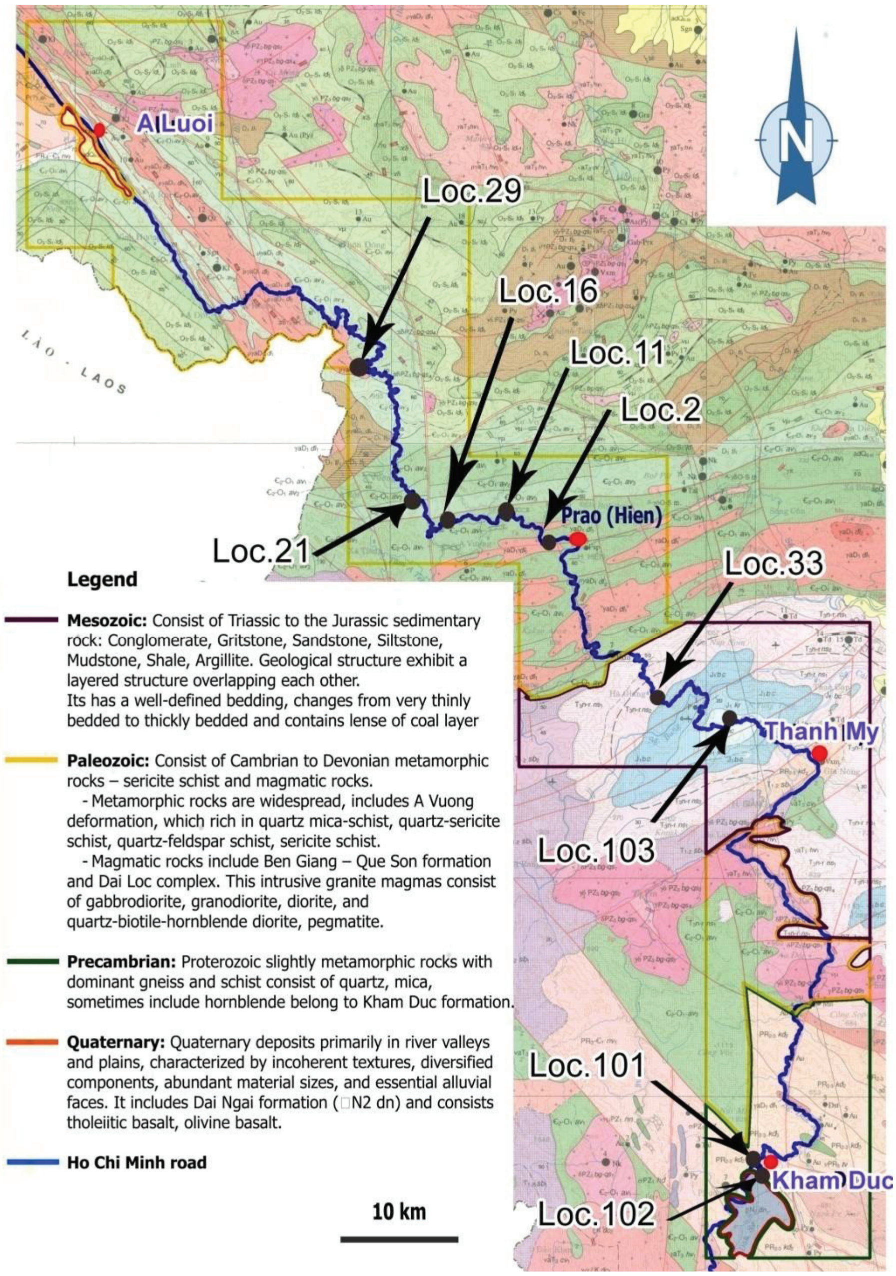


Fig.4. 21 Geological map at the sample field along the HCMR

Fig.4. 22 Surface landslides, shallow landslides (photos a, b) and the wedge type (photos c, d) on HCMR, around KhamDuc town

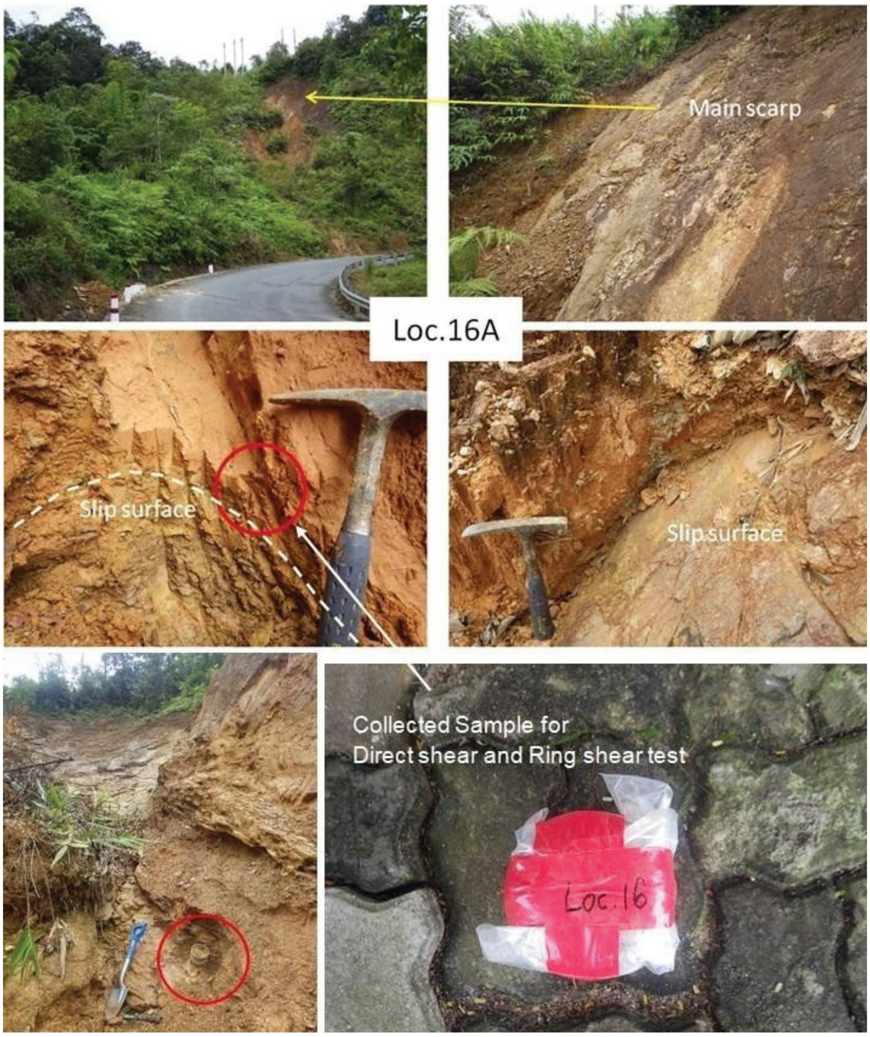


Fig.4. 23 Identified slip surface at the field and collected soil samples at landslide Loc.16A

Fig.4. 24 Collected soil samples at landslide Loc.101 on HCMR around KhamDuc aera

Tab.4. 1 Category and geological characteristics of landslides on HCMR from Prao to KhamDuc

Geological stage	Rock types	Weathering	Relation with Topography or Geology	Type of Landslide (L.S)
Intrusion (almost Paleozoic activities)	Granite Granodionite Gabbro	Not so heavy weathered	No relation	Landslide seldom are happening in this area
Jurassic Triassic	Coal, Mudstone Silt stone (shale) Sandstone Conglomerate	No weathered. Sometimes, Mudstone easily change to clay soil by slaking and smelling	1. No relation to L.S, only surface L.S. 2. Relation to geological structure (structure of rock type)	- Caused by rock type and geological structure - Might be easier to identify the signal of slip surface
Cambrian - Ordovician	Metamorphic rocks	Medium weathered. Sometimes brown color	Sometimes the relation to slope angle, erosion system and geological joint system	Wedge type L.S combined by the geological structure and weathering structure. - Surface L.S - Shallow L.S - Sometimes deep L.S
Precambrian (south part of Thanh	Metamorphic rocks (schist and some part	Two types weathering: One is heavy weathered	Relation to slope angle	- Surface L.S - Shallow L.S (2~3 m)

My, near Kham Duc)	are gneiss a little).	before Mesozoic era. Another is soft weathered after making topography (Quaternary) - Heavily weathered. - Brown to red color. - On the bottom of the river is fresh rock, very hard schist and gneiss have clear schistosity including layered mica. - Some materials change to Fe2O3,... (hematite or limonite)		(Sometimes deep sheet L.S) - Small size of L.S, but the number of L.S is much more. Sometimes, some small L.S combined together into bigger L.S.

(2) The basic field data along NH 7

NH7 located at the Western part of Nghe An province, belonging to the area of extreme tropical climate, very sensitive with a landslide. This area directly suffers by Southwest wind in summer (known as foehn wind or Laos wind), dry and hot and most active from May to August. The difference of temperature in a day is high, the ground temperature is up to 60^{o}C during the daytime but reduced to 26-30^{o}C at night. Winter is not too cold; the lowest temperature is around 16^{o}C. Rainy season varies with each location of the basin. In the area of upper Ca river, rainy season start in May and end in October. Monthly rainfall in October reached over 552.3mm at Muong Xen and 578.1mm at Con Cuong. Three months with the highest rainfall is VIII, IX, X and coincides with the annual rainy season. Floods, flash floods and landslides are common accord. The rainy season is coming later in the South, starting in June and ending in October.

The topography of this region is mostly mountainous slope areas of the Mesozoic and Paleozoic, the elevation from 200m to 1500m. This slope region was classified into landslide topography, crest slopes, valley side slopes, terrace surface group, alluvial cone and tropical tower karst. The terrain is very strong cleavage. The slope angle is generally 30 deg or more, sometimes as much as 50 deg with the cutting slope. Acording to the geological map has been published by the Vietnam Geological Survey (1995), the geology is mainly by sedimentary rocks of the Mesozoic to the Paleozoic, and limestone of the Mesozoic is finding out in eastern areas, forming the landscape of tropical tower karst. With such characteristics, the geology here is an extremely vulnerable geologic structure was produced by weathering peculiar in the tropical zone, such as generation of a weathered layer following emergence at the end of the Paleozoic, and red weathering advanced through the Quaternary. The geological disasters such as landslides are a common phenomenon on the slopes of this route, disrupt traffic and damage the road. The density of landslide is high in the west and decreases to the east. Many landslides occur along the Ca River fault.

Tab.4. 2 Annual and monthly rainfall at the stations around study area (The National Center for Hydro Meteorological Forecasting)

Rain gauge station	Month (mm)												Year (mm)
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Muong Xen	41.0	33.2	41.2	61.5	125.1	122.0	97.0	216.1	464.3	552.3	179.2	69.6	2,003
(%)	2.0	1.7	2.1	3.1	6.2	6.1	4.8	10.8	23.2	27.6	8.9	3.5	100
Cua Rao	53.7	41.5	48.9	67.5	136.0	114.7	117.1	200.9	495.6	540.8	179.3	68.2	2,064
(%)	2.6	2.0	2.4	3.3	6.6	5.6	5.7	9.7	24	26.2	8.7	3.3	100
Con Cuong	77.9	60.8	53.1	66.4	145.2	120.6	115.2	222.5	541.7	578.1	240.4	82.1	2,304
(%)	3.4	2.6	2.3	2.9	6.3	5.2	5.0	9.7	23.5	25.1	10.4	3.6	100

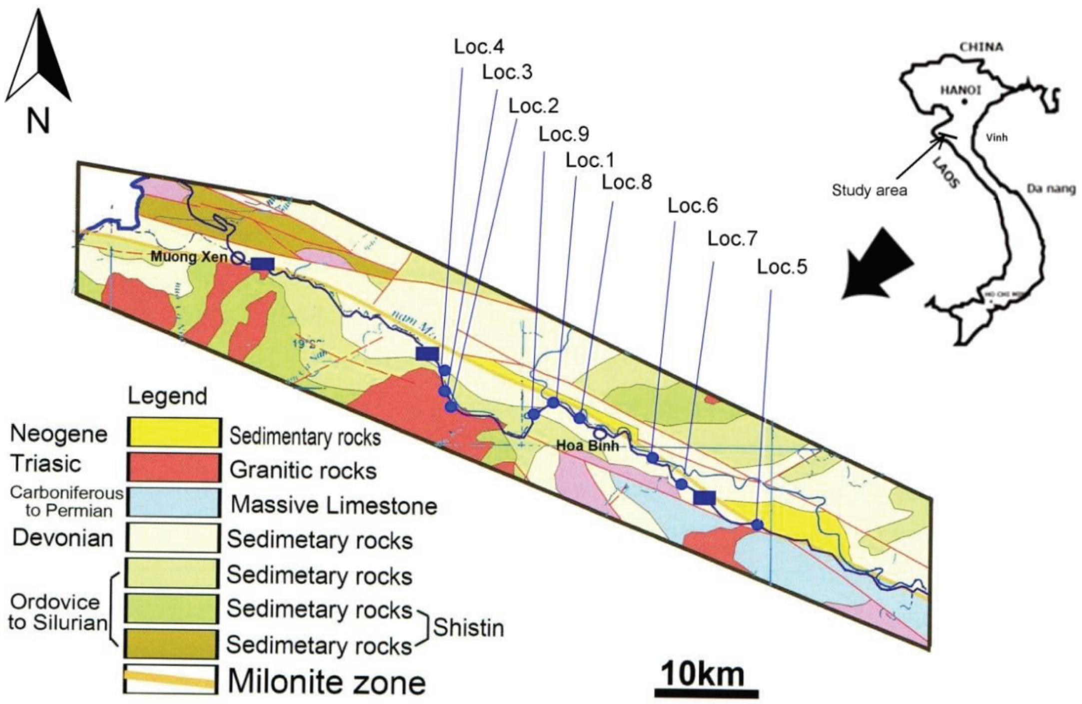


Fig.4. 25 Locations of field investigations of landslide along NH7

The investigations were conducted in April–May 2016 in the Southeast of Muong Xen town, about 70km long of NH7. This segment was parallel with Ca river and runs almost coincides with the Ca River fault zone. Fig 4.27 is overview photos of our investigated landslides along NH7.

Loc.1 Landslide is about 50m long and 10m high, although the scale is not big, but it makes cracked and damaged the pavement. A deposit of the landslide has been removed, but there are still visible horizontal cracks appearing on a slope, and the risk of reactive landslides occurs are high potential. The geology of the area is the similar sedimentary rock of the Devonian to Carboniferous period.

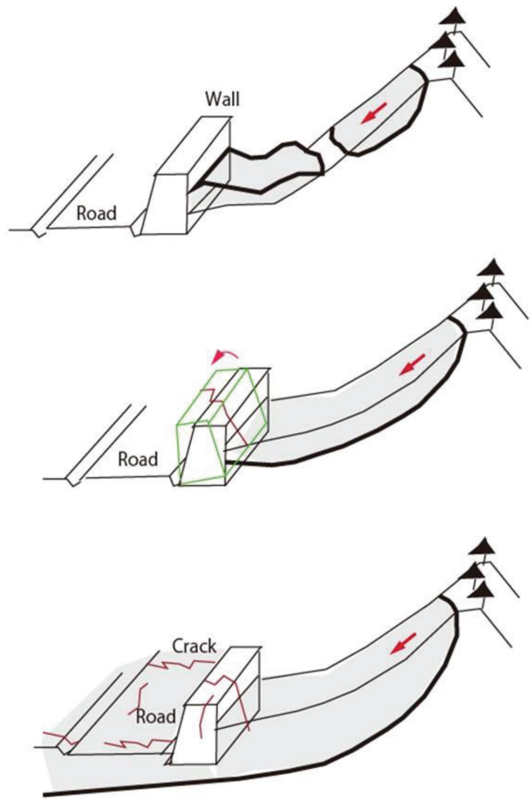


Fig.4. 26 Landslides impact on highway structures

Loc.2 is located at 19.293414 N, 104.337053 E. A part of the toe of the landslide body is located on the attack slope of the river. This slope is as steep as about 30 deg overall. The landslide lies severely breaking this slope, whose main scarp and landslide body are distinctly visible. Part of the landslide body has been deformed because it was removed for use in macadam. Presumably, sandstone and mudstone that became schist of the Ordovis period formed a dip slope structure of about 40 deg, a slip surface was formed in a part thereof to cause the landslide.

Loc.3 landslide is about 250 m wide. The toe of the landslide body was pressed out to the river. A concrete retaining wall has been built at the toe of landslides at the river side. After the landslide occurred again, it has been reinforced with gabion stone layers. But at this time, the route is deviated to the riverside by 2–3 meter and the gabion are pushed out by the landslide body of this landslide. Although this displacement is repaired annually, the continuous movement is always peeling the pavement. Concrete stairs serve also as surface drainage and grating crib works on the surface the slope are severely broken and deformed. Consequently, this landslide was verified as moving actively. The geology of the area is sandstone and mudstone that became schist of the Ordovis period.

Loc.4 located at Km175+600 at NH7, belonging to the Chieu Luu communist, Ky Son district. This section of road is 30m higher than the water level of Ca river. The height of slope is 30m and having the strike of NE and a dip of over 60 deg. Geology of sericite shale belongs to Ca river formation, soft weathered and strong cracking have been observed on and around the slope.

Fig.4. 27 The overview photos of landslides along NH7

This landslide is reverse funnel shape. It seems to be a complex type and very large scale of landslide, with the estimate of deep about 40-45m. A section 230m long of the route is deviated to the riverside by 2–3 meter and subsidence about 1m. The pavement was broken, and long cracks stretch across over the road also appeared. Concrete retaining wall at the toe of slope were broken, bent and pushed into the road. Reinforcement on the slope surface of stone masonry, the stairs and grooves are also damaged. The bottom of the slope of the river bank is reinforced with concrete retaining walls located on the bored pile foundation. However, erosion by the flow rate of river attack to deep inside of the slope, expose the pile system. This landslide occurred many times in the past, but most recently in 2011. It has moved NH7 toward the river 20m, continues to threaten to cause loss this road and fill part of Ca river.

Fig.4. 28 The field photos of Loc.4 landslide: (Left) The boundary of the landslide with the surrounding rocks is quite clear. On the surface of the landslide body has been reinforced by stone masonry, but the sliding block shifted causing the surface to break. (Right) The concrete retaining wall at the foot of the sliding block breaks and moves toward the river.

Landslide at Loc.5 was identified by air photos and 100m far from NH7 in the geology of sedimentary rock of the Devonian period. Landslides Loc.6, 7, 8, 9 are belong to geology of sedimentary rock of the Devonian period. The slope angle of LS-Loc.6, 7 are so gentle around 25 deg to 30 deg and not so high. Landslide topography of Loc.6 is alluvial cone while Loc.7 is terrace surface. The foot of the landslide body at Loc.9 was deformed and pressed out to the river. Landslides at Locs 8 and 9 seem are moving and very high potential as active. Because the deformation of road surface and concrete retaining wall were observed at outcrops of these. However, have no water or spring run out from the slope would be found during investigated.

4.3 The detail of the field investigation data along the HoChiMinh road central Vietnam.

In the fact, these landslides have ever been occurring at least one time in the past. On the site of the landslide at the moment, we can see only the temporary stable of slope, the potential of reactivation even is still high. What are the reason and mechanisms for the high risk of re-occur of these landslides in the future? Special in the humid tropical region suffered the highly weathering environmental processes like central Vietnam. In other words, it is important to understand the mechanism of reactivation. In many causes of the high risk of reactivation, the characteristic of soil strength is one of the most fundamental technical matter for recognizing the mechanism and estimate the of slope movement. Therefore, a series of detail field surveys were conducted in parallel in May and August of 2013 to clarify the characteristics of soil strength. For this purpose, the Landslide Field Inspection Sheet (LFIS) was discussed and prepared. Deformation and micro topographic features on a surface of a landslide mass observed will be filled in the LFIS. For example, Location, Properties of slope, Landslide type, Cutting slope or Natural slope, Slope direction, Slope inclination, Geological settings as Attitude of schist/ bedding/ joint plane, Rock type and other features. Some experimentations will be carried out in the field also were prepared such as handy seismograph test, Schmidt rock hammer test and the soil hardness test. In addition, soil samples at slip plane and around were collected for laboratory test (Physical properties, direct shear, ring shear, slake durability). In addition, Wen B.P et al, (2007) mentioned that one of the most important parameter to evaluate the reactivation potential of existing landslides is the residual strength of rocks at slip zones. The materials making up slip zones of existing landslides, such as old or ancient landslides, essentially behave like soils and their residual strength are commonly determined by laboratory reversal direct shear and ring shear, or in-situ direct shear tests. Therefore, estimating the residual strength of the slip zones is one of purpose of this study. For this purpose, the laboratory experiments such as direct shear and ring shear will be performed, although they are time-consuming.

The propose target area of this study is 80km length of HCMR around Prao area. Prao is a small mountain town lay on HCMR of Nam Giang district, Quang Nam province central of Vietnam. In an area of 150 square kilometers, more than 50 old and ancient landslides have been recorded, and thirty-three small scale landslide of them will be detail investigated (Fig. 4.29). Following the classification by Abe et al., (2014), the type of landslide movement in this area concentrated in four types as Slumping, Slide (Translation slide and Rotation slide), Topple and Gully. Each landslide selected has a specific characteristic that made it interesting to measure and sample.

The sites are located along a mountainous route running on highly elevated land from 200m to 1200m. We found geology of schist, sandstone, mylonite and gneiss/granite rocks spread over the study area. These rocks characterized as the strongly metamorphosed rock and schist. The deep weathering features are also developing to the rocks. The characteristics of weathering features establishes the wedge type landslide and it's easy to collapse by roadside cutting (Tien et al, 2015, 2016). Photographs show earth cuts made for road construction, which caused slope destabilization and which we identified definitively as slip surfaces.

In each landslide the soil moves over a solid mass. The transition between these two land masses is called the slip plane. This slip plane is an important feature in the study of landslides. Therefore, in every landslide a profile was needed, which showed the slip plane, the soil material underneath and above this slip plane. If this profile was accessible, it was sampled in detail. Every visible change in material was sampled. Besides disturbing soil samples, some undisturbed soil samples were taken at crucial places in the landslides such as the slip plane. The undisturbed samples were taken using PVC molds. Later, the soil samples in PVC molds were used to prepare thin sections and the rings were used to perform soil physical tests on the samples. The handy seismograph test, Schmidt rock hammer test and the soil hardness test were carried out in the field. Slip plane was observed and identified in the field (Fig. 4.30). Eight soil samples have been taken for laboratory tests, in which three undisturbed samples will be used for direct shear test and ring shear test (Fig. 4.22). Purpose of direct shear test is examining shear strength parameters (cohesion & friction angle) for evaluating slope stability, and particular the ring shear test is examining residual shear strength parameters (cohesion & friction angle) for evaluating long-term slope stability. Rocks can be classified on the basis of its degree of weathering. This type of classification is generally done on site and only by a through visual inspection rocks can be classified.

In this study, the degree of weathering can be divided into four levels are fresh rock, soft weathered, heavy weathered, and deep weathered. Fresh rock means poor chemical weathering and only soil layer developing. Soft weathered mean rocks have many cracks, and weak chemical weathering. The color usually is brown to light brown. Sometimes the original

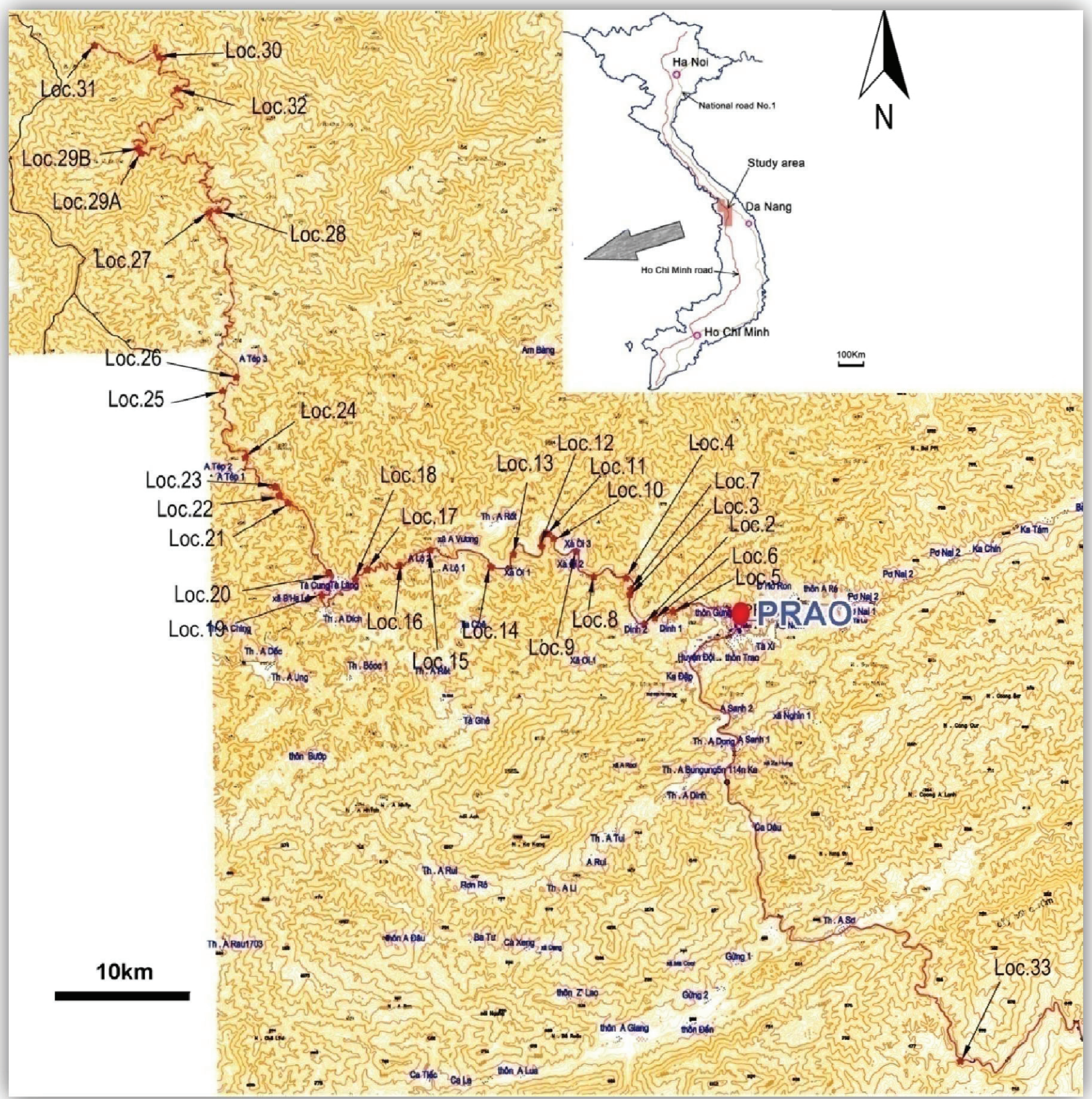


Fig.4. 29 Location of field investigations of small scale landslide along the HCMR

geological structure is deformed and angular gravel dominates. The chemical weathering process is clear. The color usually is red. Heavy weathered mean original geological structure is disappearing. The chemical weathering process affects to a whole part of landslide body. Deep weathered mean original geological structure is disappearing. All rock material is converted to soil. The chemical weathering process affects to a whole part of landslide body and minerals is changing.

Result of investigations shows almost small to medium-scale landslides along HCMR mainly caused by geological structures and weathering and by earth cuts made during road construction. It is seemed to have relation to the geological structure level of weathering and the strength of the rocks. Weathering characteristics of rock and the style of the slope movement seemed to vary depending on the soil characteristics (era and rock type). The results in Fig. 4.31 indicate that number of landslides occurred concentrate on the heavy and soft weathering geology area, up to 49% in the heavy and 34% in the soft weathering geology area. In the deep weathering geology area was occupied 14% and only 3% of number landslides were observed in the un-weathering area (fresh rocks).

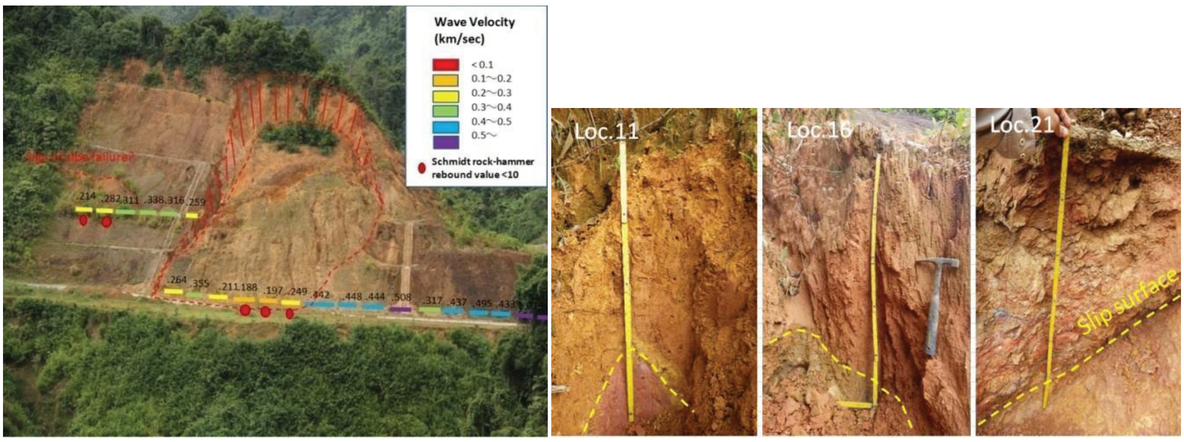


Fig.4. 30 Elastic waves velocity test at the landslide Loc.29 (left), and Schmidt Rock-hammer test and close up to identifying slip surface at the landslide sites Loc.11, 16, 21 along HCMR

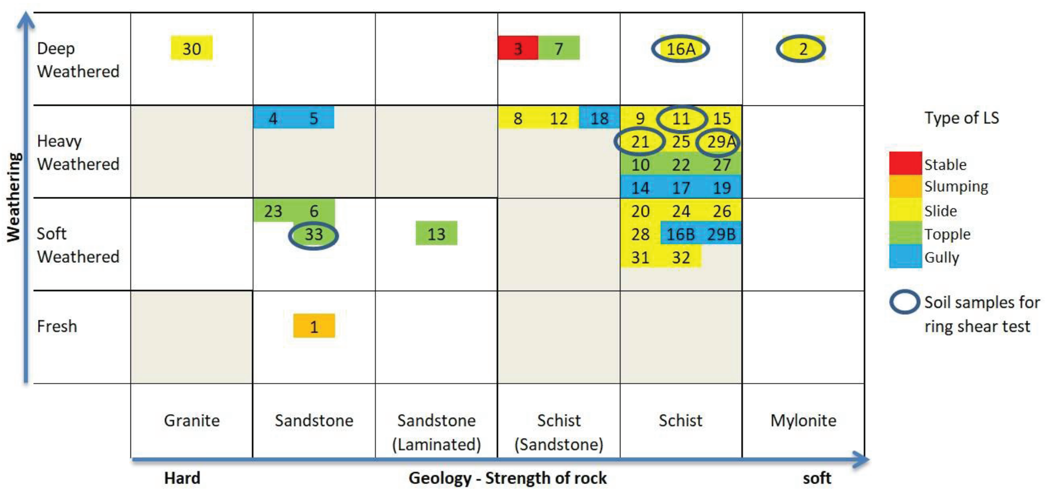


Fig.4. 31 Number of landslides based on geology types and level of weathering

The number of landslides based on geology and its percentage (Fig. 4.32) show that gully type and slide is the most common type in the areas of schist. Topple type slide is common in the area of sandstone and schist. Granite/gneiss, sandstone (Laminate) and mylonite have a small distribution and have few examples of landslides.

The results of residual strength characteristics of weathered rocks in this study will be discussed details in Item 4.4 this Chapter. Here are the LFIS of theses landslides Fig. 4.33 to Fig. 4.67.

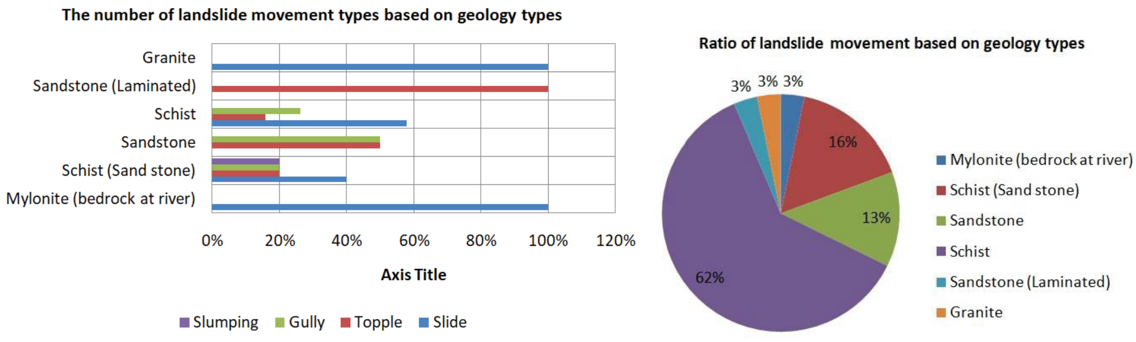


Fig.4. 32 Ratio of landslide movement based on geology types

Landslides name:	Location:	o	'	"		Landslide type:	Slumping	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.1	North latitude:	15	48	10.74	Properties of slope	(Other):	-	89	-	175	-
	East longitude:	107	53	7.19		Cutting slope or natural slope:	Cutting	Slope direction	N80E	Slope inclination	28
Name of place:	-	Km:	-			Attitude of schist/ bedding/joint plane		Strike	EW	Dip	18N
Investigator name:	N.D. Dung	T. Shibasaki	Day	20.8.2013	Geological settings	Rock type:	Sandstone, Conglomerate, Mesozoic				
Landslide Overview Figure						Other features:	Hard, fresh, partly are the bedding plain.				
					Field test:	① Handy seismograph	1	② Schmidt rock hammer	1	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		

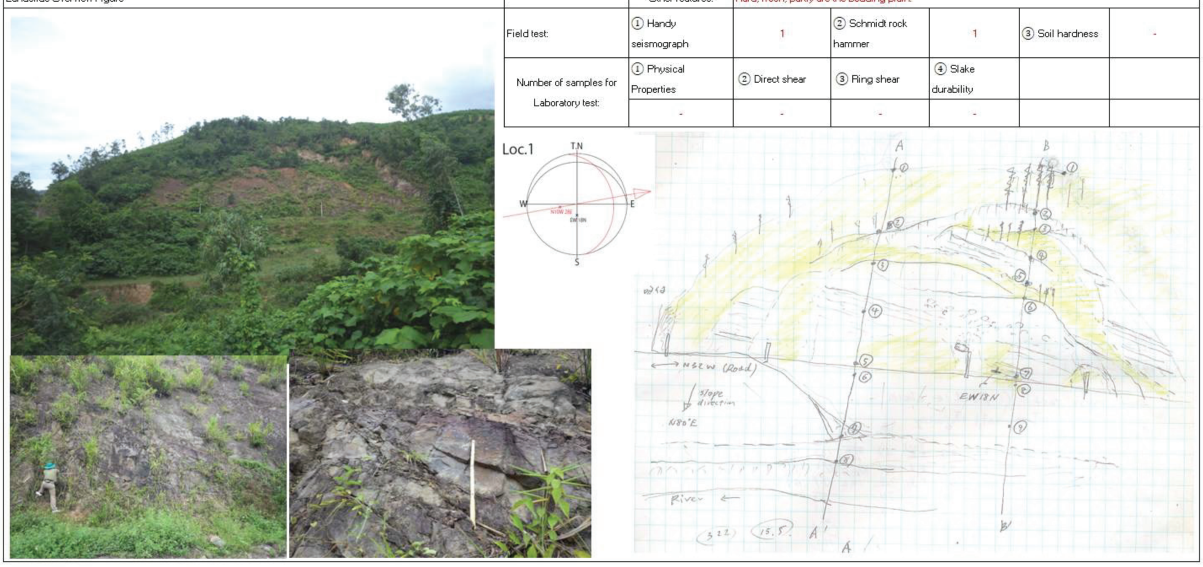
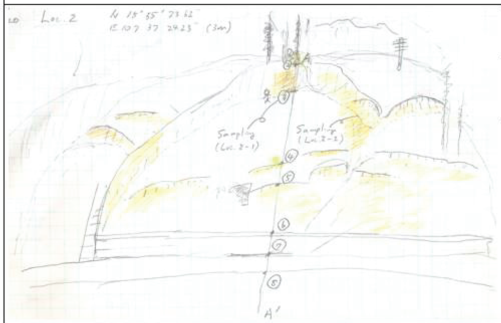


Fig.4. 33 The Landslide field Inspection sheet of Loc.1

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.2	North latitude:	15	55	23.62		(Other):	-	35	80	76	-
	East longitude:	107	37	24.23		Cutting slope or natural slope:	Cutting (Under part)	Slope direction	-	Slope inclination	-
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	?	Dip	-
Investigator name:	N.D. Dung	T. Shibasaki	Day	20.8.2013		Rock type:	Mylonite (bedrock at river)				
Landslide Overview Figure						Other features:	Graben formation at the head of the landslide with steep scarp. Lateral scarps present were some translation has occurred.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	1
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						2	2	2	-		



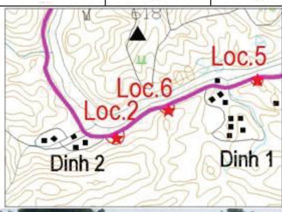
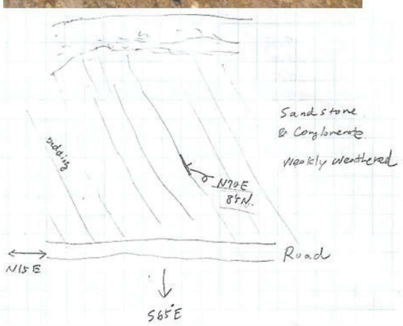
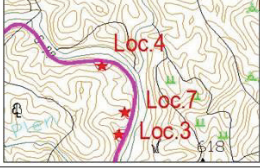


Fig.4. 34 The Landslide field Inspection sheet of Loc.2

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Stable slope	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.3	North latitude:	15	55	49.35		(Other):	-	21	-	23	-
	East longitude:	107	37	10.91		Cutting slope or natural slope:	Cutting	Slope direction	S65E	Slope inclination	45
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N70E	Dip	85N
Investigator name:	N.D. Dung	T. Shibasaki	Day	20.8.2013		Rock type:	Schist (Sandstone) and Conglomerate, Mesozoic				
Landslide Overview Figure						Other features:	Rock on slope is weakly weathered. Materials on slope is reddish yellow.				
					Number of Field tests:	① Handy seismograph	1	② Schmidt rock hammer	1	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





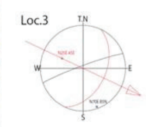
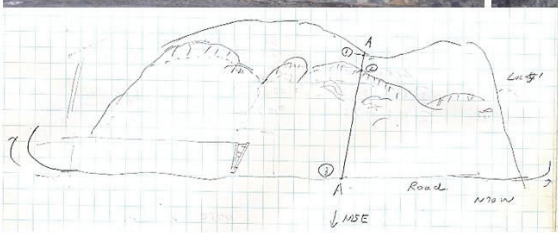


Fig.4. 35 The Landslide field Inspection sheet of Loc.3

Landslides name:	Location:	o	'	"	Properties of slope	Landslide type:	Gully erosion (shallow landslide)	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.4	North latitude:	15	56	10.43		(Other):	-	25	-	42	-
	East longitude:	107	37	7.23		Cutting slope or natural slope:	Cutting	Slope direction	N25E	Slope inclination	40
Name of place:	-	Km:			Geological settings	Attitude of schist/ bedding/joint plane		Strike	?	Dip	-
Investigator name:	N.D. Dung	T. Shibasaki	Day	20.8.2013		Rock type:	Sandstone, Mesozoic				
Landslide Overview Figure						Other features:	There are clear scarps on slope. Heavy weatheredrock on slope easy erosion by water. Many small cave on slope caused by erosion also appeared.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		



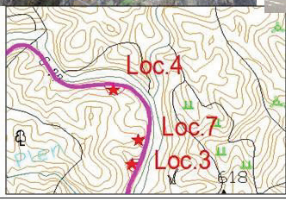
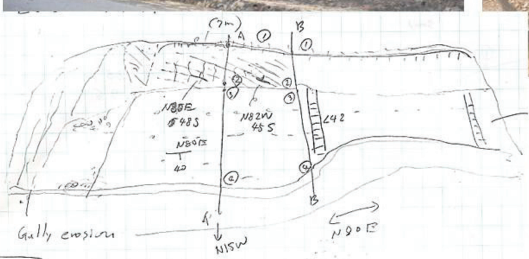
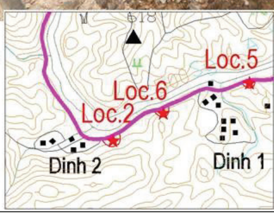


Fig.4. 36 The Landslide field Inspection sheet of Loc.4

Landslides name:	Location:	o	'	"	Properties of slope	Landslide type:	Gully erosion (shallow landslide)	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.5	North latitude:	15	55	37.17		(Other):	-	35	-	40	-
	East longitude:	107	37	54.31		Cutting slope or natural slope:	Cutting	Slope direction	N15W	Slope inclination	42
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N82W	Dip	45S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Sandstone, Mesozoic				
Landslide Overview Figure						Other features:	The lower part of slope was covered by concrete. Gully erosion developed at head and left side of the slope.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





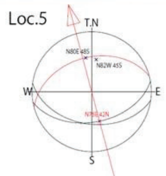
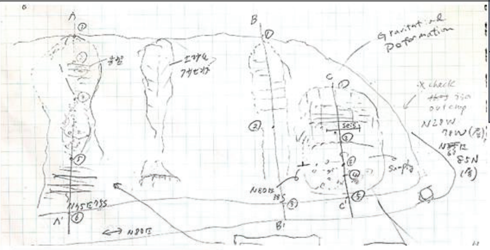
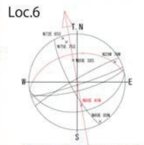


Fig.4. 37 The Landslide field Inspection sheet of Loc.5

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Topple	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.6	North latitude:	15	55	31.16		(Other):	-	43	-	49	-
	East longitude:	107	37	34.5		Cutting slope or natural slope:	Cutting	Slope direction	N10W	Slope inclination	41
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N80E	Dip	38S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Sandstone, Mesozoic				
Landslide Overview Figure						Other features:	Fresh and bare rock face with exposed discontinuities. Lack of differential weathering compared to surrounding rock faces. Tension cracks and scraps developed at head of landslide.				
					Number of Field tests:	① Handy seismograph	1	② Schmidt rock hammer	1	③ Soil hardness	-
					Number of samples for Laboratory test	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	3		







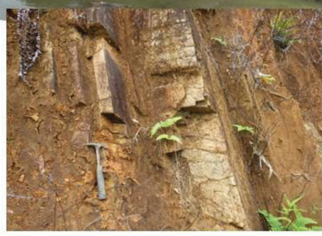
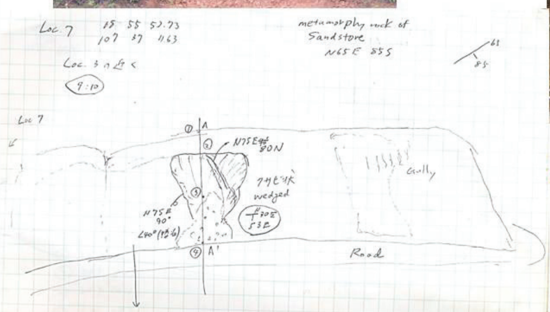
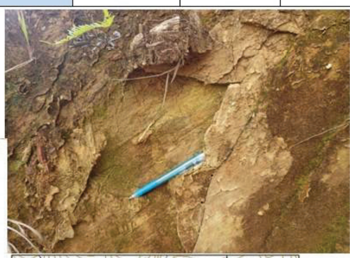
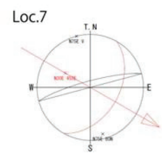



Fig.4. 38 The Landslide field Inspection sheet of Loc.6

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Topple (wedge type)	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.7	North latitude:	15	55	52.73		(Other):	-	31	-	28	-
	East longitude:	107	37	11.63		Cutting slope or natural slope:	Cutting	Slope direction	S60E	Slope inclination	45
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N75E	Dip	90
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist (Sand stone), Metamophy rock weak of sandstone				
Landslide Overview Figure						Other features:	Deep weathered rocks on slope is very high potential slide down to road, the colour change from yellow to red and easy crushed by hand.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		

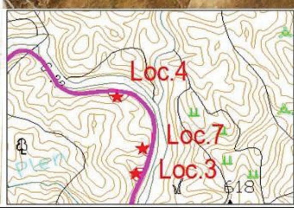
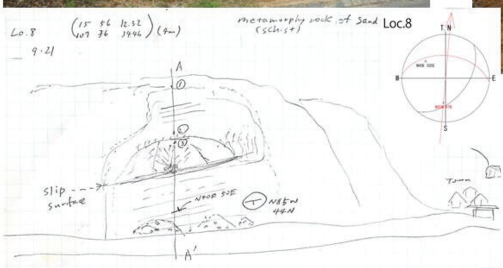


Fig.4. 39 The Landslide field Inspection sheet of Loc.7

Landslides name:	Location:	o	'	"	Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.8	North latitude:	15	56	12.32		(Other):	-	32	-	30	-
	East longitude:	107	36	34.46		Cutting slope or natural slope:	Cutting	Slope direction	N5E	Slope inclination	47
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N40E	Dip	50E
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist (Sand stone), Metamophy rock of sandstone				
Landslide Overview Figure						Other features:	Cutting slope angle by "A-A" section is 47.1 degree. Slope direction is N5E, height 32.0m, width 30.0m.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		



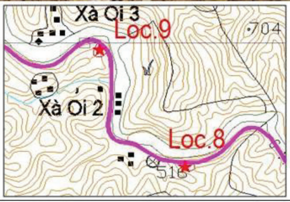
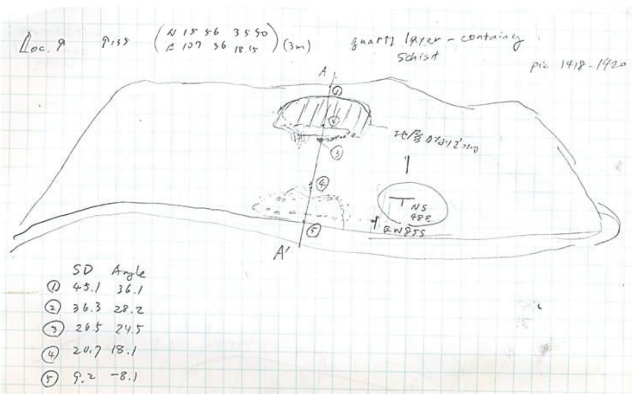
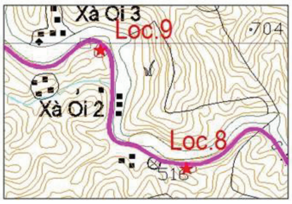


Fig.4. 40 The Landslide field Inspection sheet of Loc.8

Landslides name:	Location:	o	'	"	Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.9	North latitude:	15	56	35.5		(Other):	-	28	-	28	-
	East longitude:	107	36	18.15		Cutting slope or natural slope:	Cutting	Slope direction	E	Slope inclination	46
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	EW	Dip	85S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Quartz layer - containing schist				
Landslide Overview Figure						Other features:	Main scarp is clear and heavy weathered rock.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





Loc.9

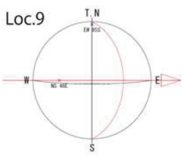
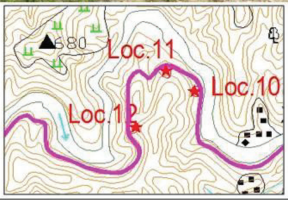
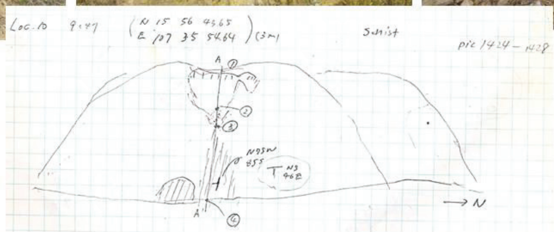


Fig.4. 41 The Landslide field Inspection sheet of Loc.9

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Topple	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.10	North latitude:	15	56	43.65		(Other):	-	40	-	37	-
	East longitude:	107	35	54.64		Cutting slope or natural slope:	Cutting	Slope direction	E	Slope inclination	47
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N75W	Dip	85S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist (Sand stone), Metamophy heavy weathered rock				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





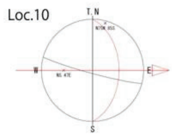
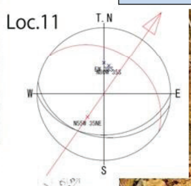
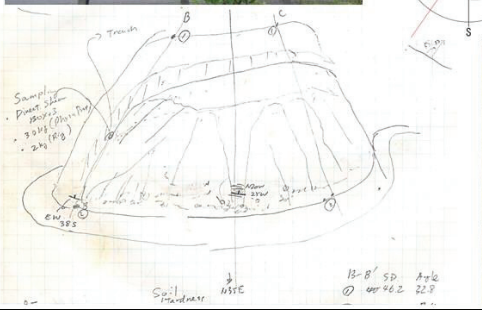


Fig.4. 42 The Landslide field Inspection sheet of Loc.10

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.11	North latitude:	15	56	53.72		(Other):	-	32	-	36	-
	East longitude:	107	35	45.79		Cutting slope or natural slope:	Cutting	Slope direction	N35E	Slope inclination	41
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N80W	Dip	35S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist (Sandstone), Mesozoic				
Landslide Overview Figure						Other features:	Slickensided slip surface.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	1
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						1	1	1	-		





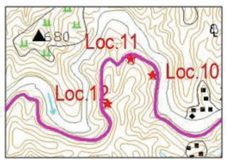
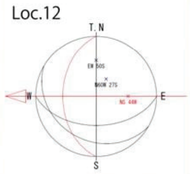
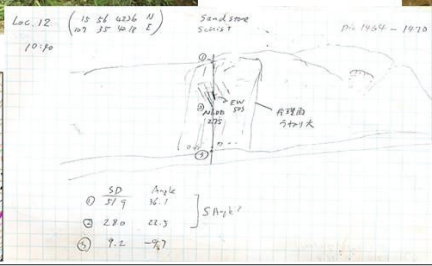


Fig.4. 43 The Landslide field Inspection sheet of Loc.11

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.12	North latitude:	15	56	42.36		(Other):	-	32	-	35	-
	East longitude:	107	35	40.18		Cutting slope or natural slope:	Cutting	Slope direction	W	Slope inclination	44
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	EW、N60E	Dip	50S、27S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist (Sand stone)				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





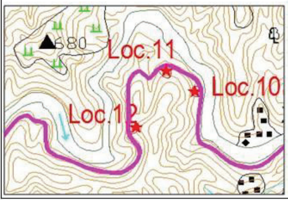
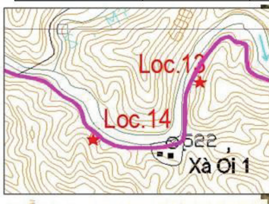
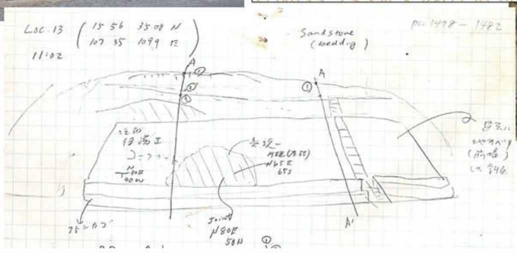


Fig.4. 44 The Landslide field Inspection sheet of Loc.12

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	? (concrete cover)	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.13	North latitude:	15	56	35.08		(Other):	-	27	-	36	-
	East longitude:	107	35	10.99		Cutting slope or natural slope:	Cutting	Slope direction	N60W	Slope inclination	39
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N65E	Dip	65S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Sandstone (Laminated)				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





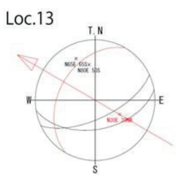
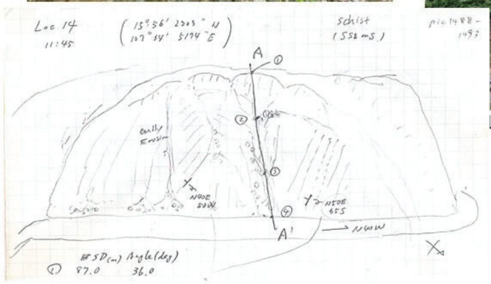
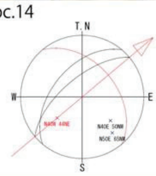


Fig.4. 45 The Landslide field Inspection sheet of Loc.13

Landslides name:	Location:	o	`	"
Loc.14	North latitude:	15	56	23.03
	East longitude:	107	34	51.74
Name of place:	-	Km:	-	
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013
Landslide Overview Figure				

Properties of slope	Landslide type:	Gully	Height of LS	Length of LS	Width of LS	Estimated depth of LS
	(Other):	-	52	-	54	-
	Cutting slope or natural slope:	Cutting	Slope direction	N50E	Slope inclination	44
Geological settings	Attitude of schist/ bedding/joint plane		Strike	N50E	Dip	65S
	Rock type:	Schist				
	Other features:	-				
Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
	-	-	-	-		





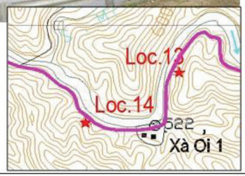
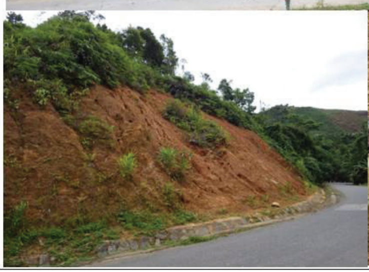
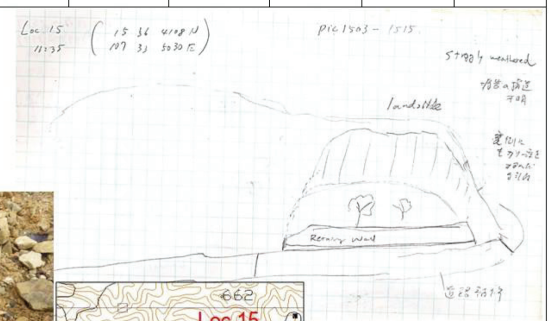


Fig.4. 46 The Landslide field Inspection sheet of Loc.14

Landslides name:	Location:	o	`	"
Loc.15	North latitude:	15	56	41.08
	East longitude:	107	33	50.3
Name of place:	-	Km:	-	
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013
Landslide Overview Figure				

Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
	(Other):	-	-	-	-	-
	Cutting slope or natural slope:	Cutting (Under part)	Slope direction	-	Slope inclination	-
Geological settings	Attitude of schist/ bedding/joint plane		Strike	?	Dip	-
	Rock type:	Schist				
	Other features:	-				
Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
	-	-	-	-		





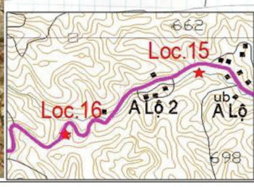
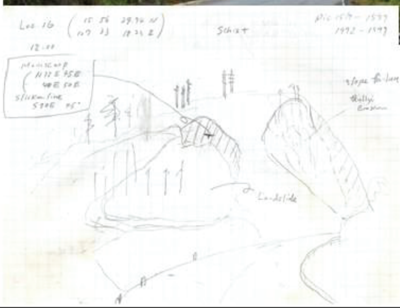


Fig.4. 47 The Landslide field Inspection sheet of Loc.15

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.16A	North latitude:	15	56	24.94		(Other):	-	37	-	35	-
	East longitude:	107	33	18.23		Cutting slope or natural slope:	Natural	Slope direction	S70E	Slope inclination	-
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N35E	Dip	45E
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	Side scarps of the landslide correspond to a fresh schistosity surface.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	1
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						1	1	1	-		

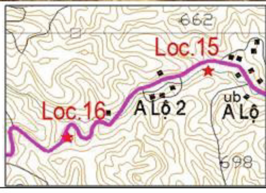
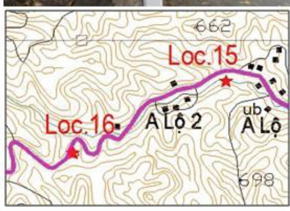



Fig.4. 48 The Landslide field Inspection sheet of Loc.16A

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Gully erosion (shallow	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.16B	North latitude:	15	56	24.94		(Other):	-	-	-	-	-
	East longitude:	107	33	18.23		Cutting slope or natural slope:	Cutting	Slope direction	N80W	Slope inclination	47
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N81E	Dip	67S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		

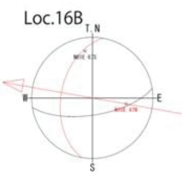
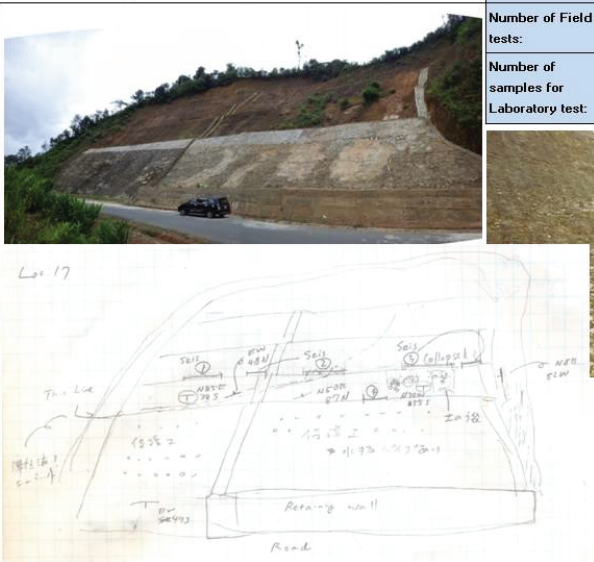
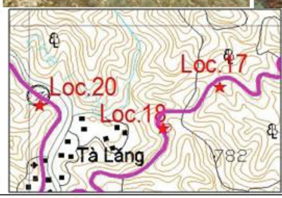



Fig.4. 49 The Landslide field Inspection sheet of Loc.16B

Landslides name:	Location:	o	`	"	**Properties of slope**	Landslide type:	Gully (concrete cover)	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.17	North latitude:	15	56	23.4		(Other):	-	-	-	-	-
	East longitude:	107	32	46.8		Cutting slope or natural slope:	Cutting	Slope direction	S	Slope inclination	47
Name of place:	-	Km:	-		**Geological settings**	Attitude of schist/ bedding/joint plane		Strike	-	Dip	-
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	Change of attitude by Folding				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





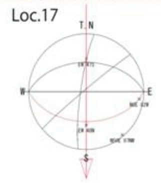
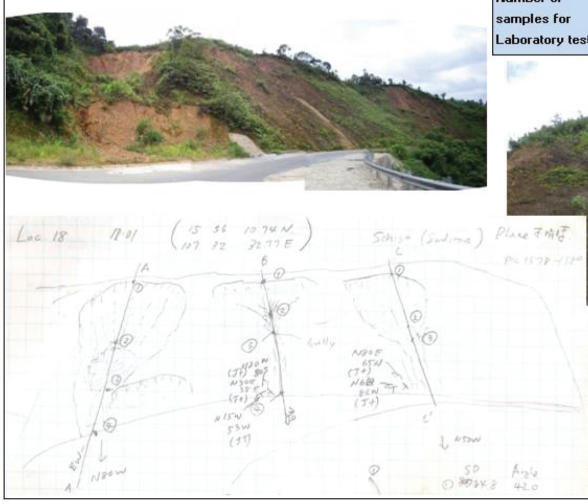
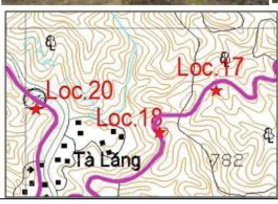


Fig.4. 50 The Landslide field Inspection sheet of Loc.17

Landslides name:	Location:	o	`	"	**Properties of slope**	Landslide type:	Gully	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.18	North latitude:	15	56	10.74		(Other):	-	53	-	69	-
	East longitude:	107	32	32.77		Cutting slope or natural slope:	Cutting	Slope direction	N80W	Slope inclination	47
Name of place:	-	Km:	-		**Geological settings**	Attitude of schist/ bedding/joint plane		Strike	-	Dip	-
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist(Sand stone)				
Landslide Overview Figure						Other features:	Joints having many directions				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





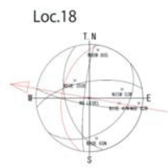


Fig.4. 51 The Landslide field Inspection sheet of Loc.18

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Gully	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.19	North latitude:	15	55	55.27		(Other):	-	39	-	43	-
	East longitude:	107	32	0.06		Cutting slope or natural slope:	Cutting	Slope direction	S20E	Slope inclination	41
Name of place:	-	Km:	425T		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N40E	Dip	85E
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





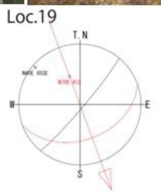
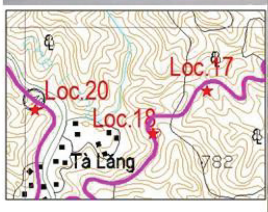
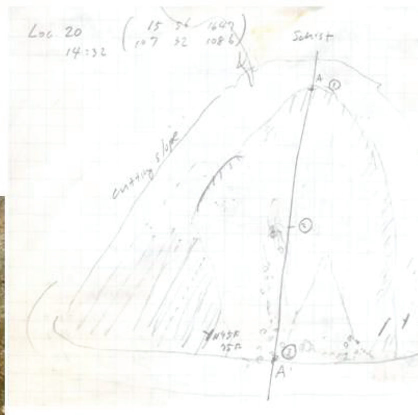


Fig.4. 52 The Landslide field Inspection sheet of Loc.19

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.20	North latitude:	15	56	16.47		(Other):	-	30	-	25	-
	East longitude:	107	32	10.86		Cutting slope or natural slope:	Cutting	Slope direction	N70E	Slope inclination	50
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N45E	Dip	75E
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		

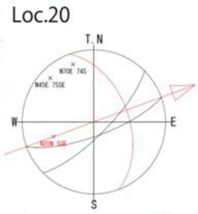
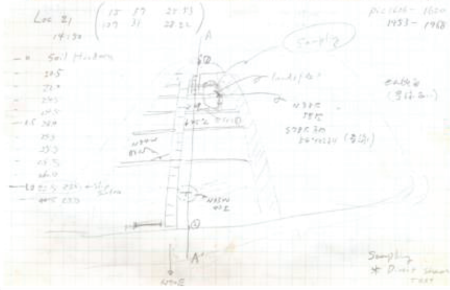
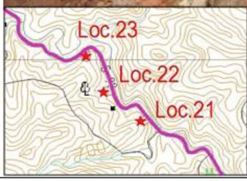


Fig.4. 53 The Landslide field Inspection sheet of Loc.20

Landslides name:	Location:	o	`	"	**Properties of slope**	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.21	North latitude:	15	57	25.53		(Other):	-	50	-	62	-
	East longitude:	107	31	28.22		Cutting slope or natural slope:	Cutting	Slope direction	N70E	Slope inclination	39
Name of place:	-	Km:	-		**Geological settings**	Attitude of schist/ bedding/joint plane		Strike	N38E	Dip	58E
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	Slickensided slip surface. Drainage works on the cutting slope were broken				
					Number of Field tests:	① Handy seismograph	2	② Schmidt rock hammer	2	③ Soil hardness	3
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						1	-	1	-		



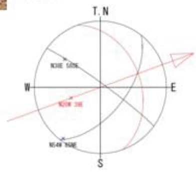
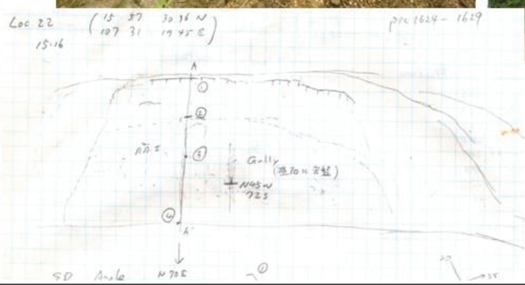


Fig.4. 54 The Landslide field Inspection sheet of Loc.21

Landslides name:	Location:	o	`	"	**Properties of slope**	Landslide type:	Topple	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.22	North latitude:	15	57	30.76		(Other):	-	56	-	80	-
	East longitude:	107	31	19.45		Cutting slope or natural slope:	Cutting	Slope direction	N70E	Slope inclination	35
Name of place:	-	Km:	-		**Geological settings**	Attitude of schist/ bedding/joint plane		Strike	N45W	Dip	72S
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		

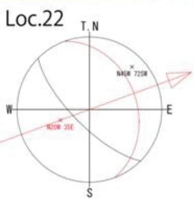


Fig.4. 55 The Landslide field Inspection sheet of Loc.22

Landslides name:	Location:	o	`	"
Loc.23	North latitude:	15	57	45.15
	East longitude:	107	31	14.53
Name of place:	-	Km:	-	
Investigator name:	N.D. Dung	T. Shibasaki	Day	23.8.2013
Landslide Overview Figure				

Properties of slope	Landslide type:	Topple	Height of LS	Length of LS	Width of LS	Estimated depth of LS
	(Other):	-	70	-	80	-
	Cutting slope or natural slope:	Natural	Slope direction	S70W	Slope inclination	35
Geological settings	Attitude of schist/ bedding/joint plane		Strike	?	Dip	-
	Rock type:	Sandstone				
	Other features:	-				
Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
	-	-	-	-		

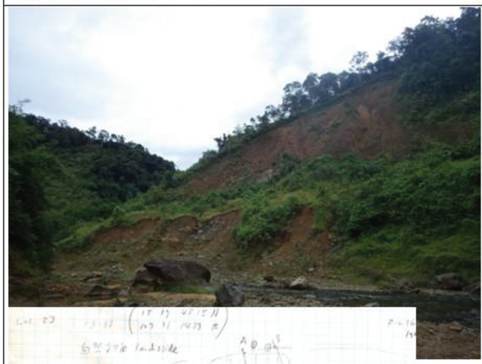
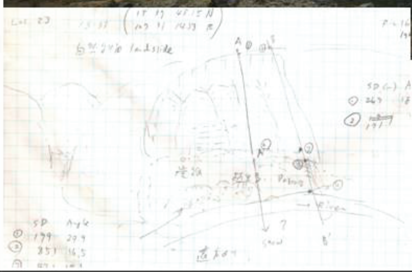




Fig.4. 56 The Landslide field Inspection sheet of Loc.23

Landslides name:	Location:	o	`	"
Loc.24	North latitude:	15	58	6.92
	East longitude:	107	30	44.75
Name of place:	-	Km:	-	
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013
Landslide Overview Figure				

Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
	(Other):	-	25	-	40	-
	Cutting slope or natural slope:	Cutting	Slope direction	E	Slope inclination	33
Geological settings	Attitude of schist/ bedding/joint plane		Strike	N35E	Dip	51E
	Rock type:	Schist				
	Other features:	Fault gouge				
Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
	-	-	-	-		

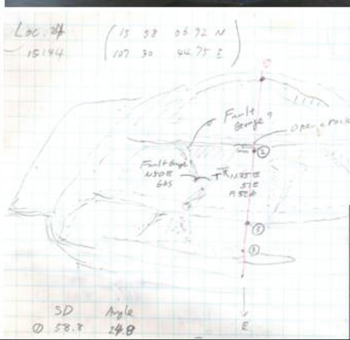
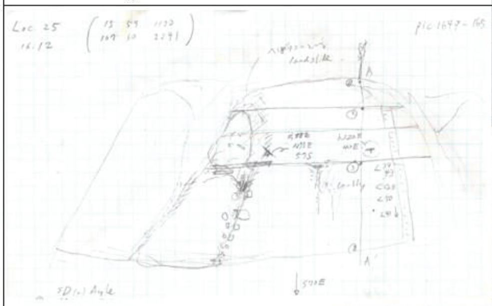
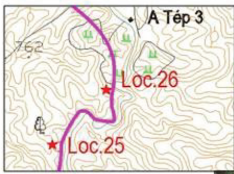






Fig.4. 57 The Landslide field Inspection sheet of Loc.24

Landslides name:	Location:	o	`	"
Loc.25	North latitude:	15	59	11.7
	East longitude:	107	30	22.91
Name of place:	-	Km:	-	
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013
Landslide Overview Figure				

Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
	(Other):	-	39	-	48	-
	Cutting slope or natural slope:	Cutting	Slope direction	S70E	Slope inclination	39
Geological settings	Attitude of schist/ bedding/joint plane		Strike	N73E	Dip	57S
	Rock type:	Schist				
	Other features:	-				
Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
	-	-	-	-		



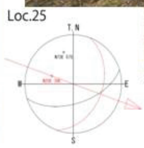
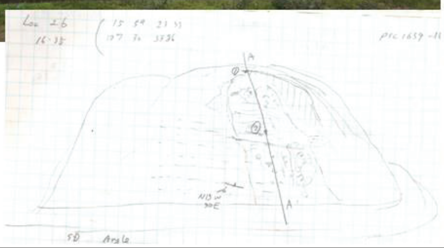
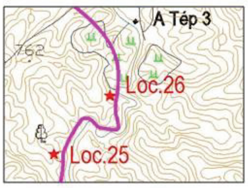



Fig.4. 58 The Landslide field Inspection sheet of Loc.25

Landslides name:	Location:	o	`	"
Loc.26	North latitude:	15	59	23.33
	East longitude:	107	30	33.86
Name of place:	-	Km:	-	
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013
Landslide Overview Figure				

Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
	(Other):	-	11	-	10	-
	Cutting slope or natural slope:	Cutting	Slope direction	S10E	Slope inclination	46
Geological settings	Attitude of schist/ bedding/joint plane		Strike	N15W	Dip	30E
	Rock type:	Schist				
	Other features:	-				
Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
	-	-	-	-		

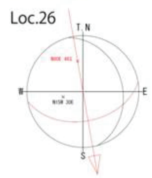
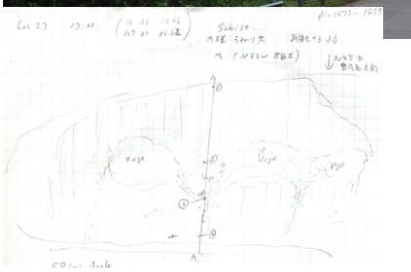
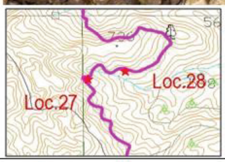


Fig.4. 59 The Landslide field Inspection sheet of Loc.26

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Topple	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.27	North latitude:	16	2	15.66		(Other):	-	76	-	79	-
	East longitude:	107	30	6.62		Cutting slope or natural slope:	Cutting	Slope direction	N45E	Slope inclination	44
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N32W	Dip	88E
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





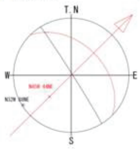
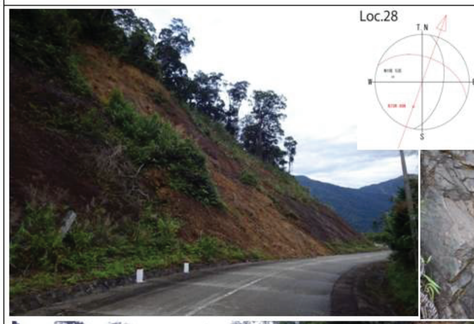
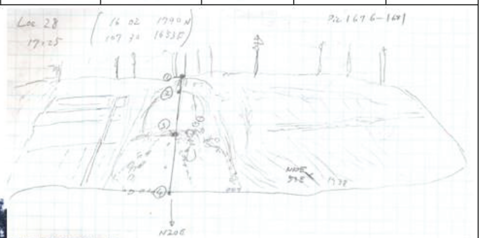


Fig.4. 60 The Landslide field Inspection sheet of Loc.27

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.28	North latitude:	16	2	17.9		(Other):	-	37	-	36	-
	East longitude:	107	30	16.53		Cutting slope or natural slope:	Cutting	Slope direction	N20E	Slope inclination	46
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N10E	Dip	53E
Investigator name:	N.D. Dung	T. Shibasaki	Day	21.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	-				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		





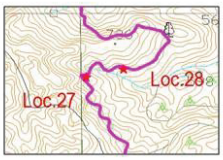
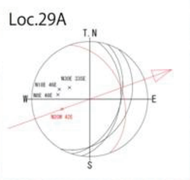


Fig.4. 61 The Landslide field Inspection sheet of Loc.28

Landslides name:	Location:	o	`	"
Loc.29A	North latitude:	16	3	20.04
	East longitude:	107	28	56.56
Name of place:	-	Km:	-	
Investigator name:	N.D. Dung	T. Shibasaki	Day	23.8.2013
Landslide Overview Figure				

Properties of slope	Landslide type:	Rotational slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
	(Other):	-	41	-	79	-
	Cutting slope or natural slope:	Cutting	Slope direction	S70W	Slope inclination	42
Geological settings	Attitude of schist/ bedding/joint plane		Strike	-	Dip	-
	Rock type:	Schist				
	Other features:	Slickensided slip surface				
Number of Field tests:	① Handy seismograph	22	② Schmidt rock hammer	22	③ Soil hardness	22
Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
	2	1	2	3		





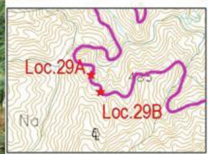
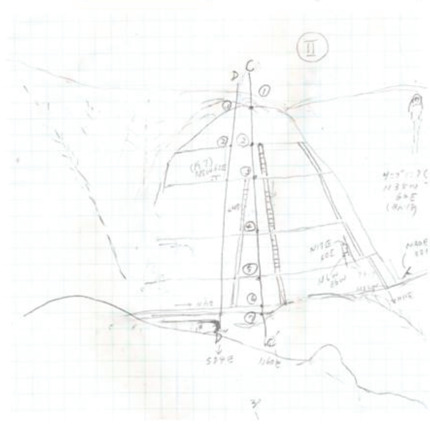


Fig.4. 62 The Landslide field Inspection sheet of Loc.29A

Landslides name:	Location:	o	`	"
Loc.29B	North latitude:	16	3	15.08
	East longitude:	107	28	59.21
Name of place:	-	Km:	-	
Investigator name:	N.D. Dung	T. Shibasaki	Day	23.8.2013
Landslide Overview Figure				

Properties of slope	Landslide type:	Gully	Height of LS	Length of LS	Width of LS	Estimated depth of LS
	(Other):	-	57	-	89	-
	Cutting slope or natural slope:	Cutting	Slope direction	N60E	Slope inclination	39
Geological settings	Attitude of schist/ bedding/joint plane		Strike	-	Dip	-
	Rock type:	Schist				
	Other features:	-				
Number of Field tests:	① Handy seismograph	10	② Schmidt rock hammer	10	③ Soil hardness	10
Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
	-	-	-	-		





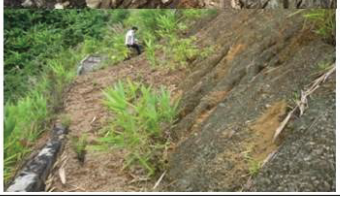
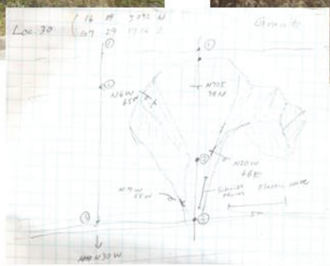


Fig.4. 63 The Landslide field Inspection sheet of Loc.29B

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Translational slide (wedged	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.30	North latitude:	16	4	50.92		(Other):	-	26	-	28	-
	East longitude:	107	29	17.14		Cutting slope or natural slope:	Cutting	Slope direction	N30W	Slope inclination	52
Name of place:	-	Km:	-		Geological settings	Attitude of schist/ bedding/joint plane		Strike	-	Dip	-
Investigator name:	N.D. Dung	T. Shibasaki	Day	23.8.2013		Rock type:	Granite rock				
Landslide Overview Figure						Other features:	Deep weathered rock at slope very easy crushed by hand. Joints having many directions. Cracks and faults in granite outcrop of Paleozoic metamorphic rocks. The wedge type slide that moves along the schistosity and crack surfaces of the formation layers.				
					Number of Field tests:	① Handy seismograph	2	② Schmidt rock hammer	2	③ Soil hardness	1
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		



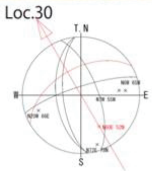


Fig.4. 64 The Landslide field Inspection sheet of Loc.30

Landslides name:	Location:	o	`	"	Properties of slope	Landslide type:	Translational debris slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.31	North latitude:	16	5	2.57		(Other):	-	167	-	189	-
	East longitude:	107	28	12.72		Cutting slope or natural slope:	Cutting	Slope direction	N20E	Slope inclination	42
Name of place:	-	Km:	389T		Geological settings	Attitude of schist/ bedding/joint plane		Strike	N33W	Dip	55E
Investigator name:	N.D. Dung	T. Shibasaki	Day	23.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	Concrete retaining wall and gabions at foot of slope were damaged and moved to the road by deposit materials of landslide caused.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	3		

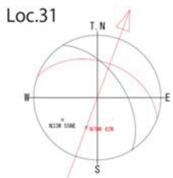
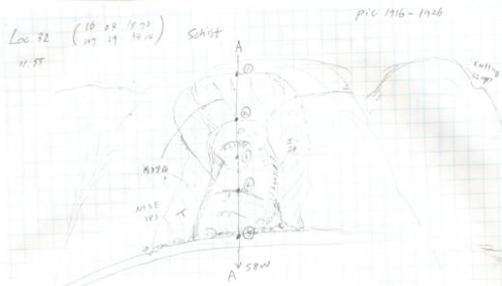


Fig.4. 65 The Landslide field Inspection sheet of Loc.31

Landslides name:	Location:	o	`	"	**Properties of slope**	Landslide type:	Translational shallow debris	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.32	North latitude:	16	4	18.7		(Other):	-	55	-	55	-
	East longitude:	107	29	34.14		Cutting slope or natural slope:	Cutting	Slope direction	S8W	Slope inclination	45
Name of place:	-	Km:	-		**Geological settings**	Attitude of schist/ bedding/joint plane		Strike	N53E	Dip	38S
Investigator name:	N.D. Dung	T. Shibasaki	Day	23.8.2013		Rock type:	Schist				
Landslide Overview Figure						Other features:	Side scarps of the landslide correspond to a fresh schistosity surface.				
					Number of Field tests:	① Handy seismograph	-	② Schmidt rock hammer	-	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						-	-	-	-		



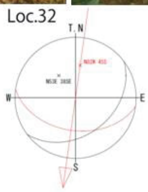


Fig.4. 66 The Landslide field Inspection sheet of Loc.32

Landslides name:	Location:	o	`	"	**Properties of slope**	Landslide type:	Translational rock slide	Height of LS	Length of LS	Width of LS	Estimated depth of LS
Loc.33	North latitude:	15	48	11.95		(Other):	-	-	-	-	-
	East longitude:	107	42	46.25		Cutting slope or natural slope:	Cutting	Slope direction	-	Slope inclination	-
Name of place:	-	Km:	-		**Geological settings**	Attitude of schist/ bedding/joint plane		Strike	N45E	Dip	20E
Investigator name:	N.D. Dung	T. Shibasaki	Day	24.8.2013		Rock type:	Sandstone, coaly mudstone				
Landslide Overview Figure						Other features:	A coal bed and black shale formation sandwiched as a slide surface				
					Number of Field tests:	① Handy seismograph	2	② Schmidt rock hammer	2	③ Soil hardness	-
					Number of samples for Laboratory test:	① Physical Properties	② Direct shear	③ Ring shear	④ Slake durability		
						1	-	1	3		

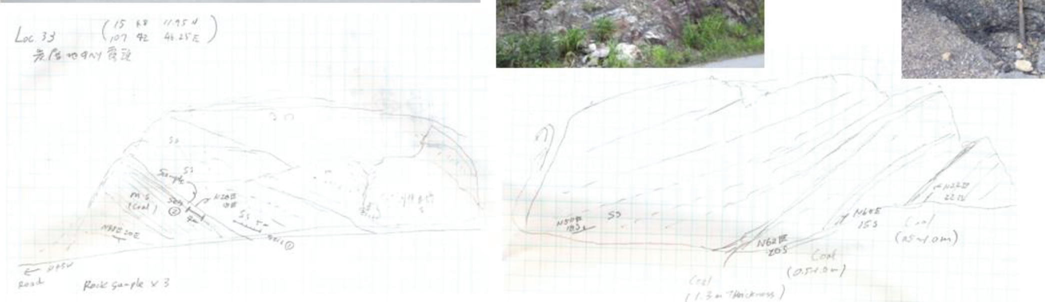


Fig.4. 67 The Landslide field Inspection sheet of Loc.33

4.4 Residual strength characteristics of weathered rock in central Vietnam

4.4.1 Introduction

In general, slope movements such as landslides are linked directly with natural disasters, which bring severe damage to area infrastructure and residents. Development activities, such as railroad and road construction, in areas with particular geomorphic and geological vulnerability will be able to trigger of slope disasters. Furthermore, the humid tropical region like the Southeast Asia is located under the highly weathering environmental processes. Therefore, prior preparation is extremely important to grasp the potential slope disaster appropriately.

For clarification the characteristic of soil strength is one of the most fundamental technical matter for recognizing the mechanism and estimate the of slope movement. The report will talk about the residual soil strength at along the Ho Chi Minh Route in the Central Vietnam. The area is in the eastern part of the Truong Son Mountains near the border of Laos Republic (Fig. 4.68). The area characterized the extreme high precipitation. It amounts reach to more than 3000 mm during the rainy season from October to January.

The Strata of Cenozoic, Mesozoic, and Paleozoic eras were found at our investigation sites along the Ho Chi Minh road. Morphological examination suggests repeated landslides of natural slopes, mostly caused by earth cuts made during road construction. Weathering characteristics of rock and the style of slope movement seemed to vary depending on the nature of the soil (era and rock type).

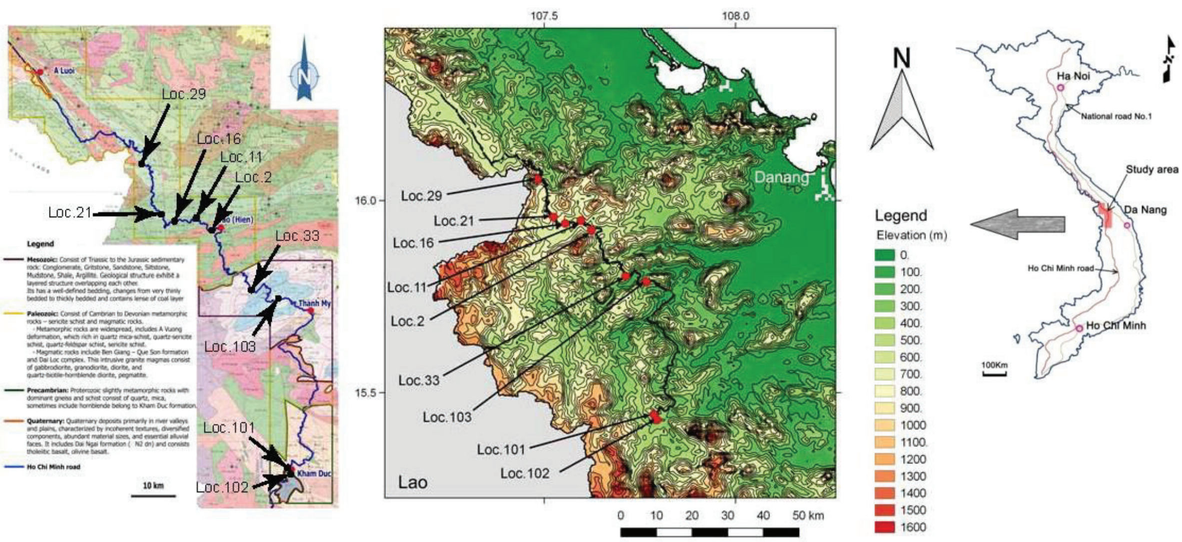


Fig.4. 68 Location of the study area. Geological map and sampling locations (Left), Topography and sampling locations (middle)

Although Rigo et al. (2006) reported residual strength characteristics of soils in a tropical zone, few experimental data were presented. Therefore, little information has been obtained in this area of study. There is a report (Dung et al, 2014) of risk evaluation study in case of small roadside active landslide along the National road No.6 might be the first trial using the residual soil strength as the scientific view in Vietnam. The combined study such as the soil residual strength, micro landform measurement, mapping and 3 dimensional safety ratio calculations lead the changing process of landslide risk.

To establish a landslide prevention policy suited to characteristics of Vietnamese national land, much more must be learned about weathering and strength characteristics of local rocks to estimate the potential for future landslides to occur.

To ascertain the characteristics of the respective strata in this study, we have gathered soil test samples from the apparent slip surface in slopes caused by a landslide or destruction of land and those from strata which seemed to form a slip surface clearly (e.g. weathered mudstone and cohesive soil).

4.4.2 Outline of investigation area

4.4.2.1 Geological and topographical features

The geological map has been published by the Vietnam Geological Survey (1997). Particularly, Luong et al. (2016) described the relationships between the geology and the types and distribution density of large scale landslide topography in the investigation area. Here we will show the outline of the geology and the topography in Fig.4.68 left and middle. We found distributions in strata of the Cenozoic, Mesozoic, and Paleozoic eras in the investigation area. The sites are located along a mountainous route running on highly elevated land from 200m to 1200m near the Laotian border.

Quaternary basalt and lacustrine deposits were found in the southern part of the investigation site around Locs. 101 and 102 in Fig.4.68. Mesozoic sedimentary rocks, alternating layers of sandstone and mudstone around located around Locs. 103 and 33. The Mesozoic establishes the clear synclinal structure. They must be a landform of a large-scale landslide, with mudstone and tuff, which are of weak strength, apparently forming slip surfaces. A number of thin coal seams distribute at the sedimentary layers. The coal layers form slip surfaces too (Luong, et al, 2016, Tien et al, 2016). The weathering feature looks clearly poor in this case of the Mesozoic. Paleozoic distributes at the northern part of the study area in the around of Locs. 2, 11, 16, 21, and 29. These rocks characterized as the strongly metamorphosed rock and schists. The deep weathering features are also developing to the rocks. The characteristics of weathering features establishes the wedge type landslide and it's easy to collapse by roadside cutting (Tien et al, 2015, 2016).

4.4.2.2 Observation of preexisting and potential slip surfaces of small scale landslides

Fig. 4.69 and 4.70 present slip surfaces of small scale landslides and the appearance of layers that must have been related to slope destabilization. Photographs labeled as Locs. 2, 16, 21, and 29 show earth cuts made for road construction, which caused slope destabilization and which we identified definitively as slip surfaces. The soil there was metamorphosed Paleozoic stratum.

The photograph labeled as Loc. 33 depicts coaly shale of the Mesozoic era, which was found at an exposure of a large scale landslide (side of end part) and which must have formed a slip surface (Luong et al, 2016). The bottom part of the sandstone was heavily weathered. Argillation was found there. The photograph labeled as Loc.103 is an exposure of a dip slope structure made from sandstone, mudstone, and tuff alternate layers of the Mesozoic era. It was found along a road and showed a geological formation of large scale landslide made from long dip slide (Luong et al, 2016). The tuff there was heavily weathered; argillation was recognized. It might eventually develop into a slip surface. The photograph labeled as Loc.11 in Fig. 4.70 portrays a free surface on a ridge. The layer had an opposite dip structure. A slope cuts made for road construction might have promoted destabilization of that layer. Countermeasure construction done later removed the movable body completely. Upon visiting that site after soil removal work, we confirmed that the weathering had penetrated into deep layers. Visual examination of the rock mass revealed the development of a black vein in the rock body. It was very thin: only a few millim scale. Furthermore, we confirmed the displacement of a rock mass along the black film vein. Separation of the sheared surface exposed a slickenside and clear striations. The slope of that striation developed on sheared surface was reconciled with the slope of landslide movement, which suggested progressive displacement and laxation in the rock mass, taking advantage of weak surface. The black color of the black vein was apparently caused by some oxide of manganese. We found many boulders of basalt on the slope in Locs. 101 and 102. We confirmed exposure of the basalt with a developed column at the upper part of the slope in Loc.102. There were boulders of basalt on the slope formed by landslides. Cohesive soil must have served as the movable body.

Fig.4. 69 Photographs showing 9 locations where soil samples were collected.

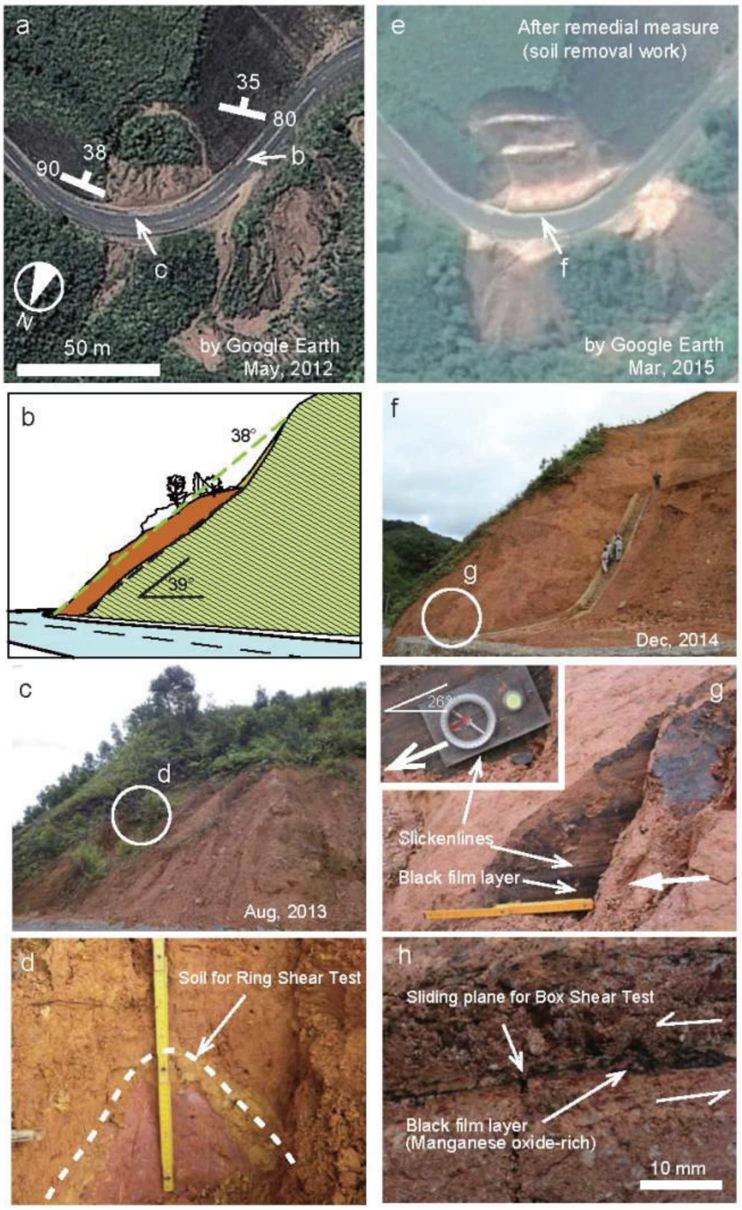


Fig.4. 70 A landslide occurring on cut slope at Loc. 11. a and e: whole views of a landslide by Google Earth image. b: Sketch of cross section of the landslide. c and d: Slip surface observed at the right flank of the landslide before remedial measuring. f, g and h: Local slickenside slip surface observed after remedial measure

4.4.3 Experimentation and the methods

4.4.3.1 Field test

A Yamanaka type soil hardness tester was used to investigate the distribution of geologic section hardness at four points of sampling. At the Locs. 11, 16, and 21, we examined the variation of hardness between the movable body and bedrock crossing slip surface (Fig. 4.71).

There are clear less hardness points at the around the slip surfaces.

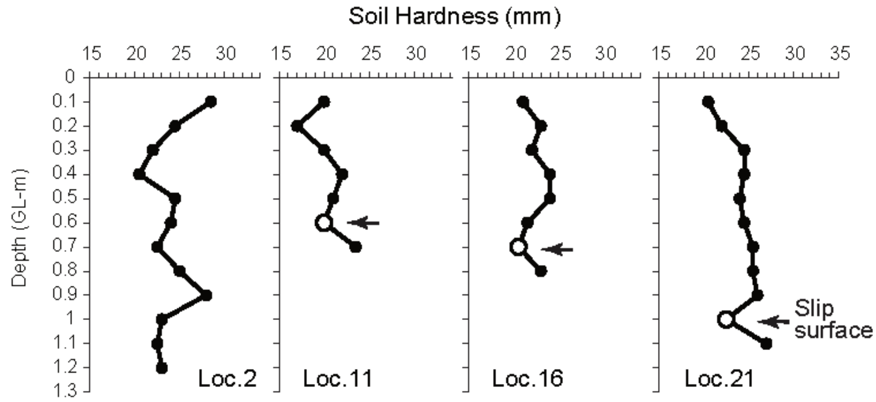


Fig.4. 71 Soil hardness profiles at the excavated outcrops. Data were measured using a Yamanaka-type hardness tester.

4.4.3.2 Physical Properties and X-ray diffraction analysis and ring shear and box shear tests

A series of soil evaluation and test carried and the data mentioned in Fig. 4.72, 4.73 and Table 4.4. Grain size tests, liquid limit tests, and plastic limit tests were applied to examine the physical properties of collected samples, along with powder X-ray diffraction tests to assess their mineral composition. Grain size test and liquid limit and plastic limit tests were done respectively in adherence to JIS A 1204 and JIS A 1205. JDX-3532 system from JEOL was used for powder X-ray diffraction tests. Conditions of tests were: Cu bulb, 25 kV of tube voltage, 40 mA of tube current and scanning velocity of 2deg. /min. Before testing the clay mineral composition, we elutriated samples to obtain oriented specimens, saturated them with ethylene glycol, and heated them at 300°C and 550°C. Residual strength was measured using a Bishop-type ring shear tester. We measured the residual strength of the sample with grain smaller than 425μm. Vertical pressure was 50–100–150 kPa and 100–200–300 kPa. The shearing speed was 0.02 mm/min at drainage condition.

We repeatedly conducted direct shear tests for the weak stratum (black film layer) sampled at Loc.11 to ascertain its shearing strength. The test was done at the slickenside sheared surface. (Procedures of Skemptom et al. (1967) and Mayumi et al. (2003) were referred).

The vertical pressure set at 25–50–100–150 kPa. The shearing speed was 0.1 mm/min.

4.4.4 Testing Results

4.4.4.1 Mineralogical properties of landslide soils

All 10 samples included quartz, which is resistive to weathering (Fig. 4.72), in addition to kaolin mineral. We detected small amounts of smectite in young strata of Quaternary soil collected at Loc. 101 and 102. At a landslide in Hoa Binh area, located 70 km southwest of Hanoi city, we investigated the mineral compositions of rock and surface soils showing different degrees of weathering (Fig. 4.73). Turning eyes on change of composition in clay mineral in the process from fresh rock to dirt, only fresh rock contained illite. Heavily weathered rock and surface soil contained kaolin instead of illite. These results suggest an environmental inclination of weathering characteristics in a warm country of Vietnam that can readily produce kaolin in the surface layer.

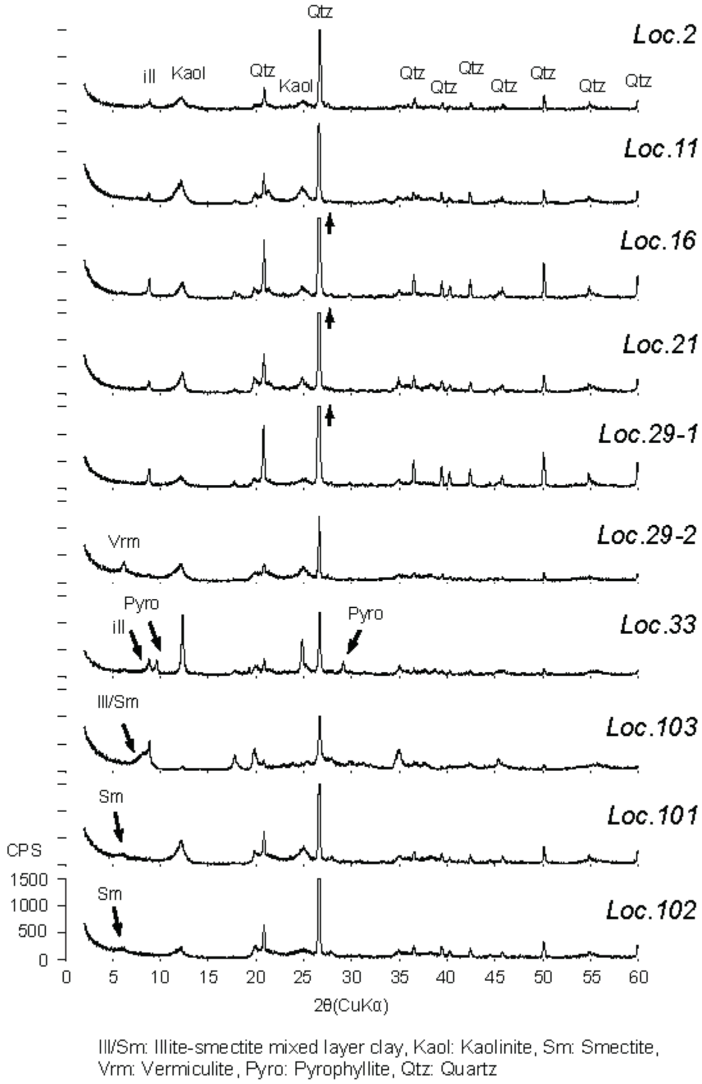


Fig.4. 72 X-ray diffraction patterns of soil samples subjected to ring shear test.

4.4.4.2 Physical properties of landslide soils

Clays in landslides found in Paleozoic stratum mostly contain some 15% of clay. They have some 45% of liquid limit and some 15% plasticity index. They all have mutually similar characteristics. Clay made from tuff found in strata of Mesozoic era (Loc. 8) and clays identified in young strata of quaternary era (Loc. 9 and 10) mostly contained smectite and mixed layer of illite and smectite, both of which are swellable clay minerals. They commonly have a high plasticity index and high clay contents. The plasticity chart of Fig. 4.74 shows that these three samples fall into the category of high liquid limit clay-silt.

4.4.4.3 Residual strength characteristics of landslide soils

Fig 4.76 and Table 4.3 presents results of ring shear test for two typical samples. Most samples from Paleozoic stratum showed angles of residual shearing resistance of 27–35°. One sample from Loc.29-2 showed a small angle of 14.0°. Inclusion of vermiculite was confirmed characteristically only in this sample. Samples from young strata contained much clay and swellable clay minerals such as smectite and mixed layer of illite and smectite. In addition, the residual shearing resistance angle was around 10°.

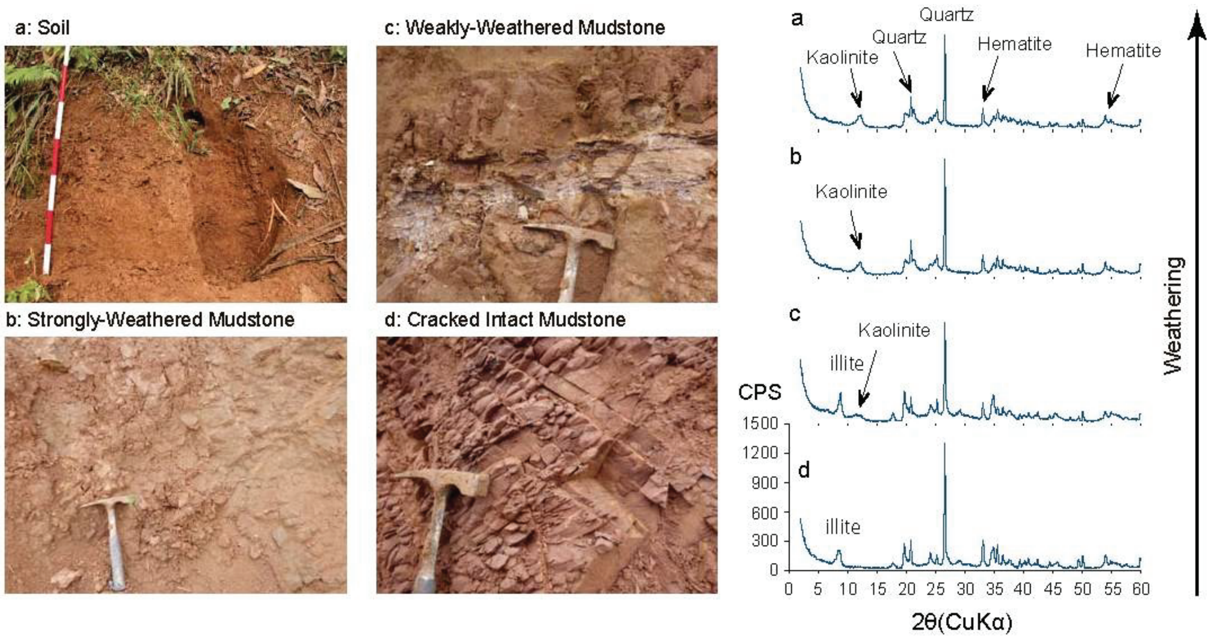


Fig.4. 73 X-ray diffraction patterns of reddish mudstone samples under varying weathering conditions. Soil and rock samples were collected from a landslide at Hoa Binh, 70 km southwest from Hanoi.

4.4.4.4 Shear strength of slickensided weak layer

We measured the shearing strength of the sample from Loc. 11 containing weak stratum with black film layer to obtain ϕ'=13.7° of shearing resistance angle (Fig. 4.77). A clay sample from Loc.11, collected in surface soil before countermeasure work, showed the angle of 28.6°, which is weaker than the sample before the work. These locally developed weak strata took several orientations. These must have been related to the local destabilization of soil and therefore introduced slope destruction. If this destruction is linked to others, it might invite a substantial decrease of shearing strength of the whole slip surface.

4.4.5 Discussion

Clay in strata of the Paleozoic era showed high strength with a shearing resistance angle of approximately 30°. However, the weak layer containing black film found in Loc. 11 and samples from Loc. 29-2 exhibited low residual strength around 14°. This strength is close to that of pure kaolin clay. If this weak layer exists, then it might develop into rock slope destabilization. The weathering environment of the investigation site seems to produce kaolinite easily at layers near the ground surface. Soil strength around 30° is significantly greater than that of pure kaolinite (around ϕr'=15). Small content shares of clay in our samples suggest that the shearing strength characteristics of soil were affected by silt–sand grains and quartz grains. In accordance with results reported for earlier studies, we confirmed that high-plasticity clays with high clay content, high plasticity index, and high liquid limit have a smaller angle of residual shearing resistance and that soils of young geologic age contain swellable clay minerals and produce high-plasticity clays (Fig. 4.78).

Location and style of slope variation in Vietnam might have been affected by the weathering characteristics of rocks composing strata and dynamic characteristics of materials in slip surface.

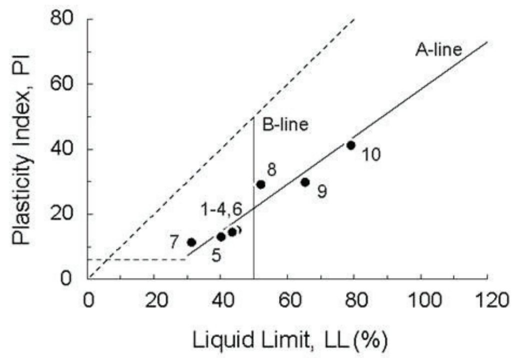


Fig.4. 74 Plasticity chart of tested soils.

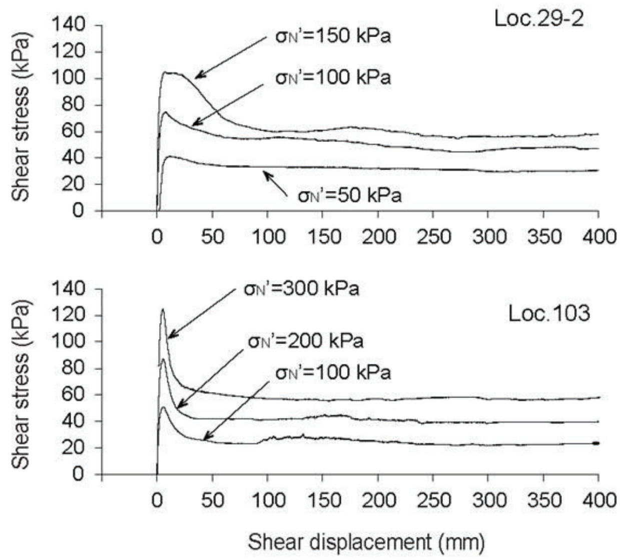


Fig.4. 75 Representative results of ring shear tests Loc. 29-2, Loc. 103).

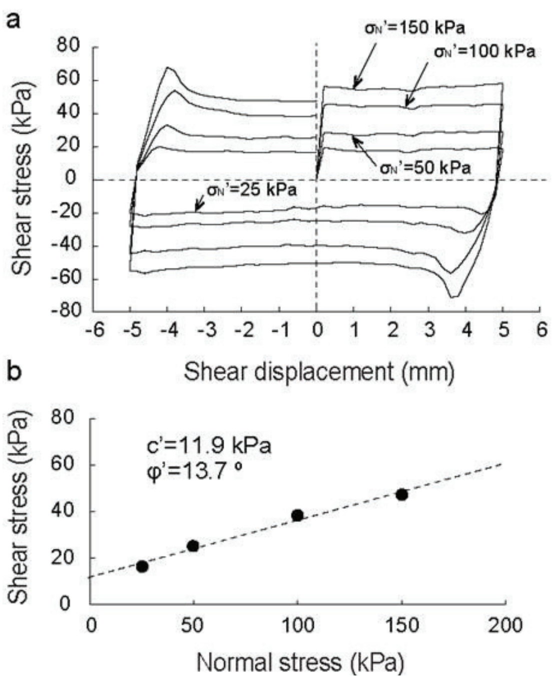


Fig.4. 77 Results of reversal box shear tests performed on an undisturbed slickenside-bearing soil (Loc. 11): a, Shear displacement vs. shear stress relationship; and b, Shear strength envelope.

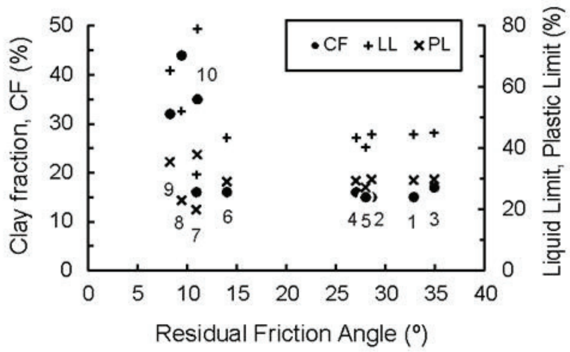


Fig.4. 76 Relationships between residual friction angles and physical properties.

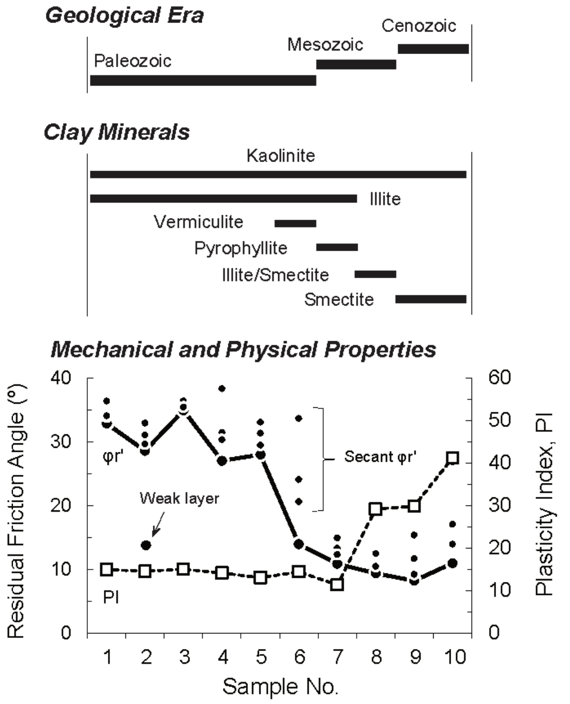


Fig.4. 78 Influence of geological setting on residual strength of soils collected from Ho Chi Minh route, central Vietnam.

4.4.6 Conclusion

We performed soil tests by collecting samples from the slopes, experienced variation, in our limited investigation sites in central Vietnam. Furthermore, we confirmed that the mineral composition and physical characteristics differ depending on the geologic age and that their residual strength changes similarly. Especially, younger strata has a smaller angle of residual shearing resistance. In Japan, Mayumi et al. (2003) reported a difference of slip surface strength between strata as well. Countermeasure work in Vietnam should be planned at each slope after the elucidation of their dynamic respective characteristics. We hope for future accumulation of information related to the geological features of each stratum.

Tab.4. 3 Physical and mineralogical properties of testing soils.

Sample No.	Location	Geology	Grain Size (<425 μm)			Index Property			Mineral Assemblages
			Sand 63-425 μm	Silt 2-63 μm	Clay <2 μm	*LL* (%)	*PL* (%)	*PI*	*Ill/Sm: Illite-smectite mixed layer clay, Kaol: Kaolinite, Sm: Smectite, Vrm: Vermiculite, Pyro: Pyrophyllite, Qtz: Quartz*
1	Loc.2	Paleozoic, Mylonite	28	57	15	44.5	29.5	15.0	Qtz>Kaol>Ill
2	Loc.11	Paleozoic, Schist	13	72	15	44.4	29.8	14.6	Qtz>Kaol>Ill
3	Loc.16	Paleozoic, Schist	34	49	17	44.9	29.8	15.1	Qtz>Kaol>Ill
4	Loc.21	Paleozoic, Schist	20	64	16	43.5	29.3	14.2	Qtz>Kaol>Ill
5	Loc.29-1	Paleozoic, Schist	31	54	15	40.2	27.1	13.1	Qtz>Kaol>Ill
6	Loc.29-2	Paleozoic, Schist	16	68	16	43.5	29.0	14.5	Qtz>Kaol,Vrm>Ill
7	Loc.33	Mesozoic, Coaly Shale & Sandstone	29	55	16	31.3	19.9	11.4	Qtz,Kaol>Pyro
8	Loc.103	Mesozoic, Tuff, Mudstone & Sandstone	5	51	44	52.1	22.9	29.2	Qtz>Ill,Ill/Sm>Kaol
9	Loc.101	Cenozoic, Basalt & River Deposit	15	53	32	65.4	35.5	29.9	Qtz>Kaol>Sm
10	Loc.102	Cenozoic, Basalt & River Deposit	17	49	35	79.1	37.9	41.2	Qtz>Kaol>Sm

Tab.4. 4 Results of ring shear test.

Sample No.	Location	Fully Softened Strength		Residual Strength				
						Cr'=0	Cr'≠0	
		Cs' (kPa)	φs' (°)	σ_N' (kPa)	τ_r/σ_N'	Secant φr' (°)	Cr' (kPa)	φr' (°)
1	Loc.2	7.6	33.5	50 99 150	0.736 0.672 0.675	36.4 33.9 34.0	3.9	32.9
2	Loc.11	13.3	32.4	47 86 147	0.602 0.647 0.569	31.1 32.9 29.6	5.0	28.6
3	Loc.16	6.8	34.0	45 81 129	0.734 0.737 0.711	36.3 36.4 35.4	2.2	34.9
4	Loc.21	16.1	30.0	34 80 126	0.790 0.611 0.585	38.3 31.4 30.3	9.0	27.0
5	Loc.29-1	11.7	33.4	99 199 299	0.651 0.609 0.565	33.0 31.3 29.4	11.6	28.0
6	Loc.29-2	10.8	32.8	45 100 145	0.665 0.447 0.376	33.6 24.1 20.6	18.9	14.0
7	Loc.33	12.1	23.2	99 191 292	0.267 0.237 0.219	15.0 13.3 12.4	8.2	10.9
8	Loc.103	14.9	20.1	98 201 300	0.222 0.191 0.185	12.5 10.8 10.5	6.6	9.4
9	Loc.101	13.2	24.3	100 200 301	0.275 0.207 0.163	15.4 11.7 9.3	6.7	8.3
10	Loc.102	11.0	27.1	97 200 300	0.506 0.307 0.249	26.8 17.1 14.0	18.0	11.0

4.5 Some trials of landslide risk evaluation as the actual safety factor calculations.

4.5.1 Case study at Km95 Landslide on National Highway 6

The landslide along the National Highway 6 of the Hanoi suburbs, near Hoa Binh province will be introduced as a case study. Although this landslide is not huge, the state immediately after disaster generating is indicated comparatively in detail. Moreover, an understanding is also advancing a series of field survey. The current field investigations are, make up the micro landform classification map for the realization the slope movement tendency, clarify the geological structure and soil strength, and landslide topography measurement by laser survey. Based on these, the 3 dimensional landslide stability analyses will be carried by ADCALC3D. By the series of study, the overall perspective will be realized.

4.5.1.1 Introduction of the KM95 landslide

The target landslide belongs to Hoa Binh province, located at 95 km far from the starting point of NH6 at Hanoi. The road is linking Vietnam Capital City and Northwestern provinces of Vietnam. Route length is 504 km and the road goes through 4 provinces and cities (Ha Noi, Hoa Binh, Son La and Dien Bien). Section travel through Hoa Binh province is 119 km long (from Km 39 to Km 158). In 2001, this route was the renovation and upgrading of the section from Hoa Binh to Son La (from Km 78+300 to Km 303+790) with a grade - III in Vietnamese standards on mountainous of road and completed on March 2005.

Since being put into operation, this section has promoted investment efficiency, service better for the travel and transportation of goods and people efficiently serves the construction of Son La and Lai Chau hydropower plant and the role of transnational routes. Unfortunately, after reoperation this route, the phenomenon of landslides and rocks from slopes fall down the road very often, concentrated on the section from Km78+300 to Km 158.

Because this road is an important artery. The traffic is highly frequent and many people use for daily life. There is hundreds of landslide distribution along this road and some of them are still very active. In the area of Hoa Binh province, there are around 30 landslides and 17 of these landslides are active. Among them, the Km 95 landslide occurred in December, 2009. The size of the landslide was about 100 m in width, 80 m in height and deduced the depth 10~20 m. It's located at a part of the small peninsula like topography. The toe part is exposed to the road surface and uplifting is also occurring.

Ministry of Transport and People's Committee of Hoa Binh Province carried the urgent inspection and carried the urgent repair work. That is cut the deformed micro topography and cleaned the surface. The concrete frame works for surface adjustment carried. And concrete steps sat not only for the walking but also for the water discharge. Although, during the job, the new scarp has been appeared in the behind higher part of the countermeasure area. The displacement of the scarp was getting larger and larger. The plan of it is typical horseshoe and the top part displacement is to reach to 1.5 m high vertical. According to such new deformation, the temporal water discharge and shut the infiltration works had carried. It is just setting the small spillway and outlet. The bottom of scarps part was filled with clay. The spillway by concrete was also sat. The scarp deformation was stopped. After the urgent countermeasure work, there are no secondary features of landslide phenomena (Fig. 4.80).

Fig.4. 79 Overview of the Km95 Landslide located at NH6 (photo taken in March 2014)

Fig.4. 80 Some micro features of Km9onlandslide (photos taken in Aug. 2013)

Fig.4. 81 Some distinctive shallow landslide characteristics around Km95 landslide (left) and Relatively fresh rocks at nearby the landslide area (right)

4.5.1.2 Tendency of land and geologic features at the surrounding area

The site of Km95 landslide is located in the part of the peninsula shape area. There was no typical landslide topography. But the surface features have some distinctive shallow landslide characteristics (Fig. 4.81 left).

The geology consists of Mesozoic sedimentary rocks such as reddish medium sandstone, mudstone. The structure has some inclination, but the dominant dip and strike are developing slightly against the dip direction of the direction of Km95 landslide. The weathering tendency is deeply and strongly developed (Fig. 4.81 right). The soil strength data and material characteristics are also evaluated. Soil samples had taken at nearby the landslide area. Because there are similar landslide features are occurring. A soil sample at S1 location will be tested to determine the residual strength of weathered rocks. Three soil samples at locations S2, S3, S4 were used for testing material characteristics (Fig. 4.82).

4.5.1.3 Material characteristics

X-ray diffraction analysis

Clay mineral characteristics of the weathered materials are examined by X-ray analyzer. Soil faces are categorized to crack rock (S3), laminated rock (S4), strongly weather rock (S2) and soil (S1). The result of testing is very clear. That is, relatively flesh rocks include iolite at the S3 location. But according to the weathering advance, kaolinite getting appears at locations S1, S2 and S4 (Fig. 4.83).

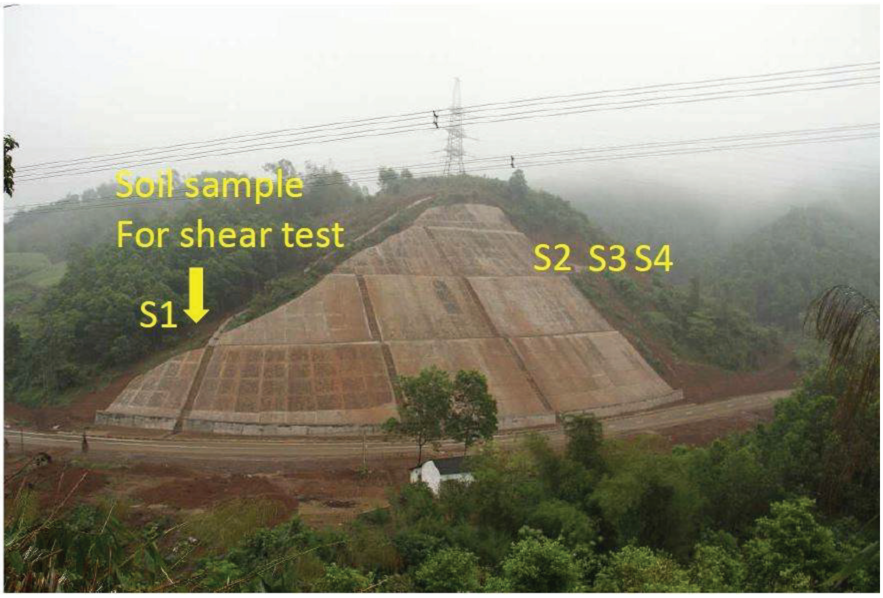


Fig.4. 82 Locations to take soil samples at Km95 landslide

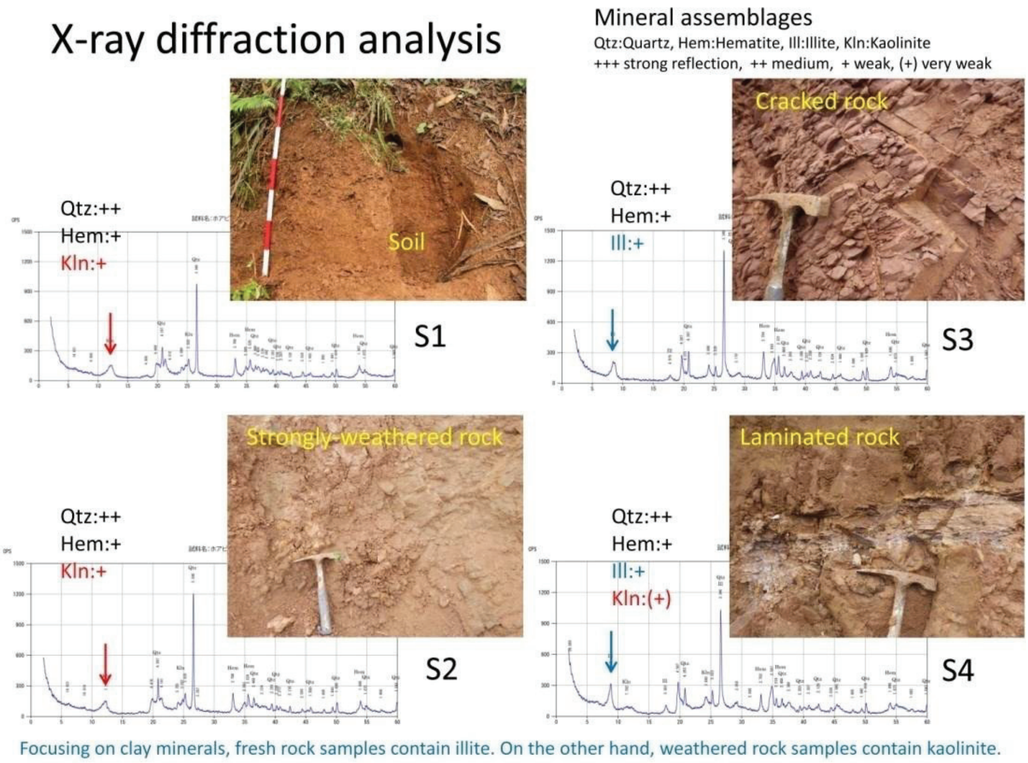


Fig.4. 83 Data of the X-ray diffraction analysis

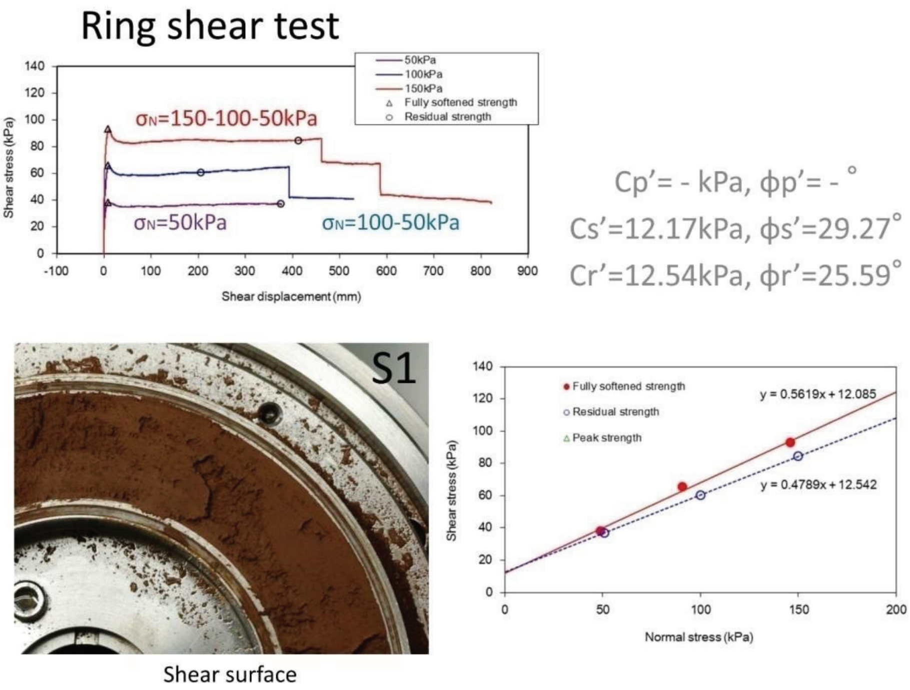


Fig.4. 84 Data of the ring shear test at the Km95 landslide

Soil strength of the area

Residual strength was measured using a Bishop-type ring shear tester. Fig 4.84 presents results of the ring shear test for S1 sample. The angle of residual shearing resistance of 25.59°.

4.5.1.4 Safety factor evaluation by ADCALC3D

The series of estimations were tried by using the relatively convenient three dimensional calculation software, ADCALC3D. ADCALC3D has three types of 3D landslide stability analysis: Hovland, Janbu3D and RBSM3D. The initial data of the landslide topography had taken in 2011 at the occasion of set up the countermeasure (by Consultant Company). The other data by means of the topography after the countermeasure carried that had taken at last March 2014. The topographic features are transferred to X.Y.Z digital data (Fig. 4.85). Fig. 4.86 is the 3D image of the Km95 landslide area (left) and deduced slip surface structure (right). The methodology of deducing is based on micro features on field investigation and data on the occasion of set up the countermeasure taken by Consultant Company in 2011. Although, according to the actual field displacement by the developing cliff, this case seems the typical and simple slump type landslide. And the toe part was also appearing as the budging at road. We carried the series of safety factor evaluation. The calculation approach of slope stability analysis RBSM3D. Fig. 4.87 is the results of estimations. The initial FS set at 0.9704 because of the actual landslide phenomena. And recalculate by the data of C and ϕ, the FS marked as 1.1914. The estimation after the urgent countermeasure condition, the FS marks 1.2357. This shows the safety level improved 5%. But the 3D image shows the high stress concentration area at toe part (red colour zone).

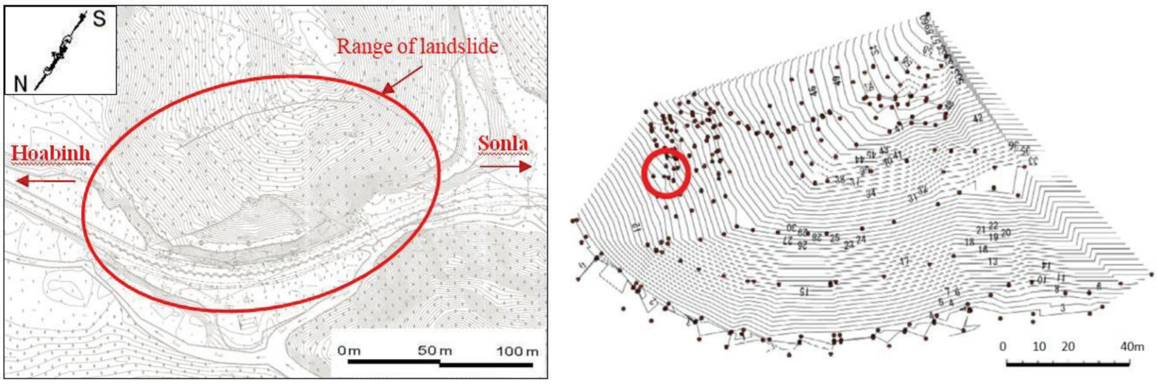


Fig.4. 85 Contour map of the Km95 landslide, taken in 2011 at the occasion of set up the countermeasure (left) and Digital data of landslide after the counonrmeasure carried, taken at last March 2014 (right).

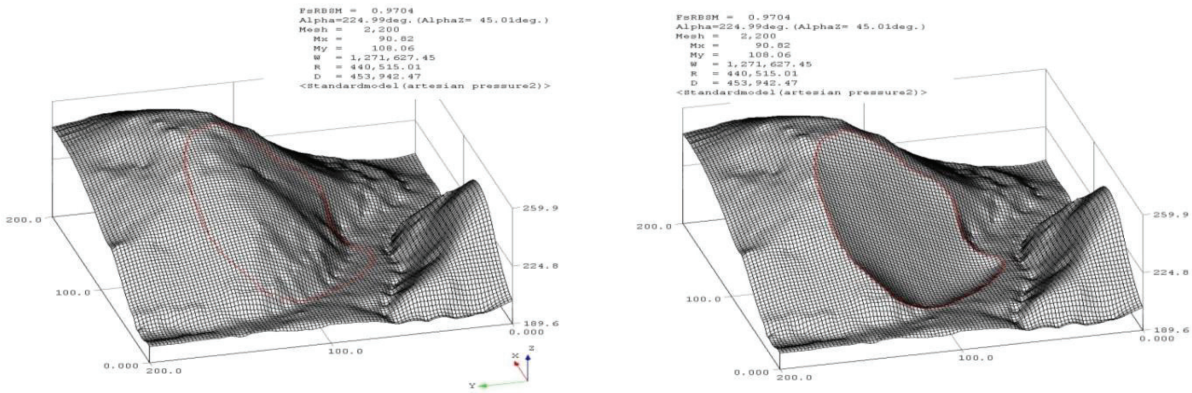


Fig.4. 86 The 3D image of the Km95 landslide area (left) and deduced slip surface structure (right)

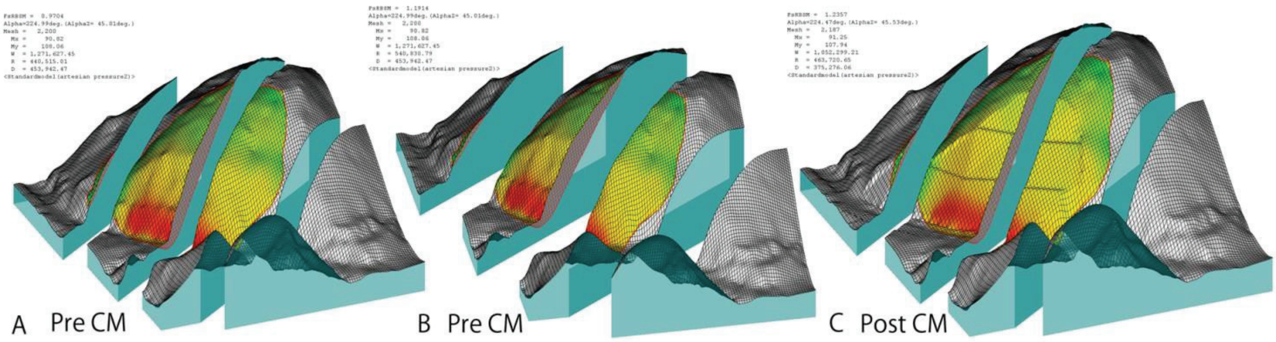


Fig.4. 87 The 3D image of the FS estimation carried by ADCALD3D

Tab.4. 5 The results of estimations of FS at Km95 landslide

Title	C	ϕ	γ	Fs	R	D
Unit	KPa	o	KN/m3		KN	KN
Pre-cut	10	25	18	1.19	540,831	453,942
Pre-cut & C=0	0	25	18	0.97	440,515	453,942
Post-cut	10	25	18	1.24	463,721	375,276

4.5.1.5 Discussion

Fig 4.86 (left) shows the topography of the before the disaster 2009. According the map, there is the typical landslide topography at the eastern side of the Km95 landslide. At year 2012, clear and large horse shoe shape cliff stretched at the upper slope of the area of counter measure. The cliff stretched to the eastern side of the Km95. There is clear and small landslide topography. The similar scale of Km95 landslide might be located in many areas. These landslides are not so huge, but if it's moving, the materials move to the road. The amounts will much enough the take human's life. Then, we must pay attention to these landslides. And if there are a number of such landslide risks, we have to consider the way of the technique of evaluation of its instability and construct the way of decision making system for getting the most reasonable way of monitoring, countermeasure, field inspection etc.

4.5.2 Trials of landslide risk evaluation - Cases study on HCMR

After clarifying the characteristics of soil strength and deduced the slip surface of landslides, the sensitivity analysis for stable or unstable condition using RBSM3D by ADCALC3D will be carried in some case study. The sensitivity of FS in the condition of groundwater level is assumptions change. It is similar to the actual condition of groundwater before and after the rainy season in Central Vietnam. Landslides at Loc. 29 and Loc. 101 along HCMR will be discussed as case studies in this study.

4.5.2.1 Case study at Loc.029

Landslide Loc.029 is a wedge-shaped slip that occurred in 2009, which was on HCMR around Prao town in the central of Vietnam. Many field surveys are conducted from 2011 to 2015. Fig. 4.88 is stereo pair photographs of Landslide Loc.29. Evidences at the field and the wedge type of landslide show that it occurred by the rainy season. There are three slip surfaces, including two slip surfaces on the main scarp-side wall N10W 40NE (③), and sides of the N40E 50SE (②) and the slip surface N40E 30 (①) at the bottom (Fig. 4.89). Because of this slip plane is the end point (the right hand side: the north side) from the base side: has become a form of stick to the road surface toward the (left side of the south). Also confirmed a situation where base side is overhanging before as slope, is observed the remnants of a compression hill in the part of the road valley of the base side. There is no groundwater or spring was observed around the surface of the slope during several degrees of exploration. In fact, it is expected that there are many sandy components and high water permeability is high in terms of particle size. Therefore, because water is relatively easy to dissipate, it is highly likely that groundwater will not be stored (Void) if rainfall continues without rain. However, because there are clear gully erosion marks on the legs, it is natural to think that heavy rain suffered from the influence of water (surface water to groundwater) and that temporary groundwater was stored and the wedge part slipped. The geology is red of strongly weathered schist.

The stability analysis algorithm was adopted RBSM3D. This technique has become a model with statically indeterminate problems between slices by solving the stiffness matrix, it is also an advantage slip direction and the strain distribution is found.

Fig.4. 88 A stereo pair photographs of Landslide Loc.29

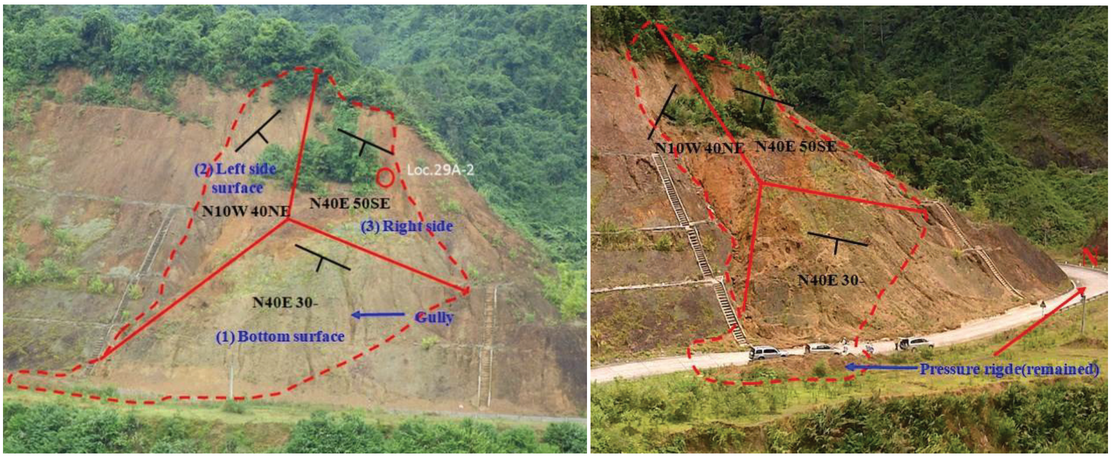


Fig.4. 89 Landslide Loc.29 on Ho Chi Minh route

For the soil constants "29 A-2" which has the peak intensity, the total softening strength and the residual strength sampled from the right side wall of the test value are adopted. γt = 18 kN/m3 was adopted in view of the fact that the unit weight γt has a density of 1.75 to 1.85 g/cm3 in many weathering zones of similar sample points. Since this area occurs during the rainy season of 2009, we assume the following.

1) Peak intensity before disintegration topography (before), Fs> 1.0 with no groundwater (Void).

2) Under some groundwater conditions (maximum at Full), even peak intensity in the Pre-collapse topography (before) would have slipped with Fs <1.0.

3) It can be predicted that the Post-collapse topography (after) will have peak intensity and the groundwater condition of ② will be stable at Fs> 1.0.

4) It is also possible to assume that after sliding once, part or all of the slip surface has decreased in residual strength.

Here, in addition to the Full and Void, groundwater level condition is set so that groundwater is distributed in parallel from ① face (bottom face). + 1 m means that it is 1 m above the ① face.

The calculated results are shown in Table 4.6. We do not satisfy assumption conditions 1) to 3) up in case 001-004. On the other hand, in case 001 where the water level rises from 4 m, Fs = 0.990 (<1.0) in the Pre-collapse topography (before). On the other hand, the Post-collapse topography (after) is Fs = 1.040 (> 1.0) and rises by 5% compared to before the occurrence, satisfying the conditions 1) to 3), consistent with the slip surface shape and the soil condition. In other words, it can be inferred that the groundwater level rose by about 4 m or more.

Next, case 006 to 010 are the results of the sensitivity analysis on the stability of the post-collapse topography (after) by changing the distribution of the soil param with peaks and residuals and changing groundwater conditions.

Case 006 is Fs = 0.873 when the residual strength is placed on the entire surface (①②③) under the condition of +4 m water level, so it will not be said that the safety factor will be considerably reduced every time heavy rain is given.

In case 007, only the bottom surface ① is the residual strength, and the side wall ② ③ is the peak strength. The result, it is almost reasonable to assume that Fs = 0.960 under the water level condition of +4 m, and it can be assumed that it becomes slightly unstable. Therefore, allocation of soil constants is judged to be roughly reasonable.

By the way, it is expected that the critical point of the water level is between + 3 m and +4 m when Fs = 1.031 when the water level condition + 3 m (case 008). Also, assuming that there is no water level at present, Fs = 1.278 are sufficiently stable (case 009). Even if the groundwater is empty, even if the strength becomes the residual strength, Fs = 1.095 (case 010).

Tab.4. 6 Sensitivity analysis for stable or unstable condition of Ls-Loc.29 using RBSM3D

Case	File Name	c' ϕ' condition (assumed by ShearTest)						Ground water condition	Output			Safty Factor	
		Part①		Part②		Part③						Before	After
		c'(kPa)	ϕ' (°)	c'(kPa)	ϕ' (°)	c'(kPa)	ϕ' (°)	From Bottom	R(kN)	D(kN)	Direction	Fs	Fs
001	Loc029-before-0001	16.11	23	16.11	23	16.11	23	Full	48,255	108,978	244.0	0.443	-
	Loc029-Lafter-0001								50,324	89,434	242.8	-	0.563
002	Loc029-before-0002	16.11	23	16.11	23	16.11	23	Void	118,022	91,628	242.3	1.288	-
	Loc029-Lafter-0002								108,631	77,967	241.6	-	1.393
003	Loc029-before-0003	16.11	23	16.11	23	16.11	23	+2m	105,526	93,660	241.7	1.127	-
	Loc029-Lafter-0003								96,181	80,024	240.9	-	1.202
004	Loc029-before-0004	16.11	23	16.11	23	16.11	23	+3m	100,261	94,653	241.6	1.059	-
	Loc029-Lafter-0004								90,892	81,017	240.7	-	1.122
005	Loc029-before-0005	16.11	23	16.11	23	16.11	23	+4m	94,808	95,749	241.4	**0.990**	-
	Loc029-Lafter-0005								85,378	82,111	240.6	-	**1.040**
006	Loc029-Lafter-0006	18.90	14	18.90	14	18.90	14	+4m	71,691	82,111	240.6	-	**0.873**
007	Loc029-Lafter-0007	18.90	14	16.11	23	16.11	23	+4m	78,812	82,111	240.6	-	**0.960**
008	Loc029-Lafter-0008	18.90	14	16.11	23	16.11	23	+3m	83,531	81,017	240.7	-	**1.031**
009	Loc029-Lafter-0009	18.90	14	16.11	23	16.11	23	Void	99,612	77,967	241.6	-	**1.278**
010	Loc029-Lafter-0010	18.90	14	18.90	14	18.90	14	Void	85,349	77,967	241.6	-	**1.095**

In other words, it is expected that long-term stabilization can be achieved by laying precautionary groundwater exclusion (pipes, etc.) even if groundwater is not always on the main slip.

The slip direction in the calculation has the main axis in the direction expected in the S60E direction. In the analysis results, there is a clear compressed part of the hissing legs, so it is expected that even if a slight suppressed embankment + retaining wall is applied to the terminal part, the stability will be increased and it can be an effective countermeasure. In this case it is sufficiently possible to slightly shake the road line to the valley side.

4.5.2.2 Case study at Loc.101

Next case study is a shallow landslide on HCMR, in Kham Duc area (Fig 4.90). The Kham Duc town belongs to Quaternary zone, geological structures are usually flat, including lake deposits with extremely weak layers such as organic rich, peat and clayey layers, and volcanic rocks with intruded basalt consolidate hard and heavy rock. The lake deposits are black, reddish brown, but the weathering level is not so deep. The boundary of the volcano and lake deposits is black deeply weathered material, with many holes because of the lava gas. Lake sediments are deeply weathered and changed to clayey materials. Landslides occur as rotational slides along river side slopes, with a complex of small to surface landslides and soil creeps.

Field investigation at Ls-Loc.101 in December 2014 shows that is not a big landslide, but this is a combine of some parts of small failures. The shape of landslide before occur were estimated by measuring at field combine with the contour topographic map was prepared from W3D data. Soil samples were collected at scarp and at guess slip surface of the landslide. Ring shear test to determine the Residual strength of soil and other test at the laboratory for soil physical characteristics param. The sensitivity analysis for stable or unstable condition of Ls-Loc.101 using RBSM3D, in no groundwater condition (Void) and in full on groundwater condition (Full). The unit weight γt = 18 kN/m3 was adopted in view of the fact that the unit weight γt has a density of 1.75 to 1.85 g/cm3 in many weathering zones of similar samples on HCMR.

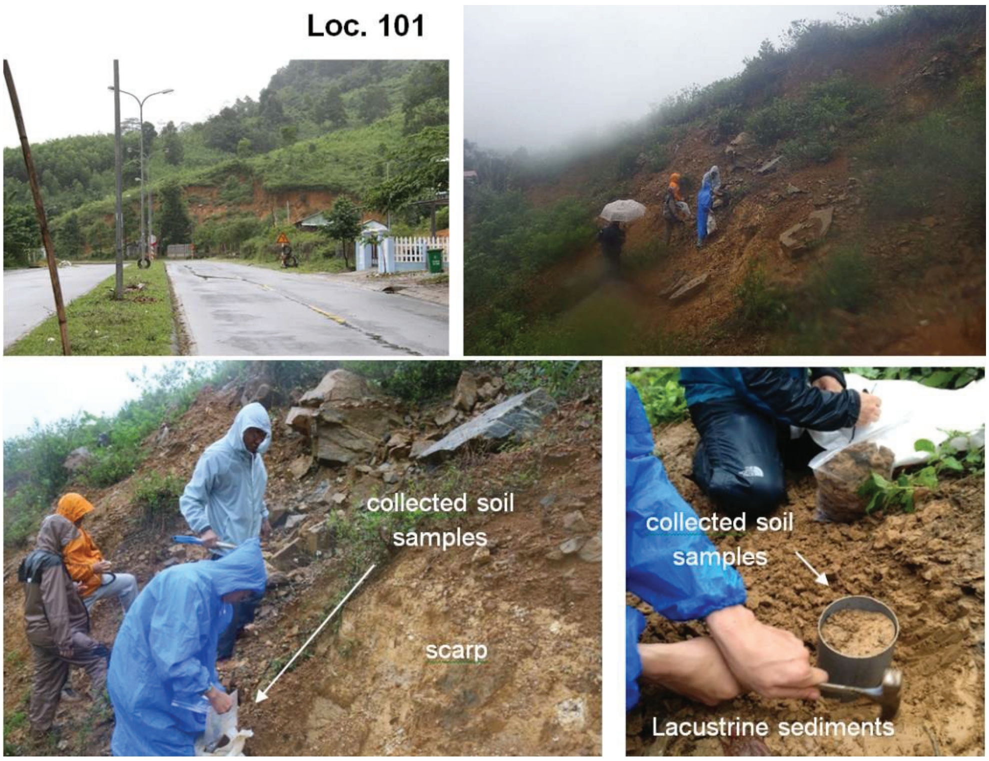


Fig.4. 90 Collected soil samples at Loc.101 landslide

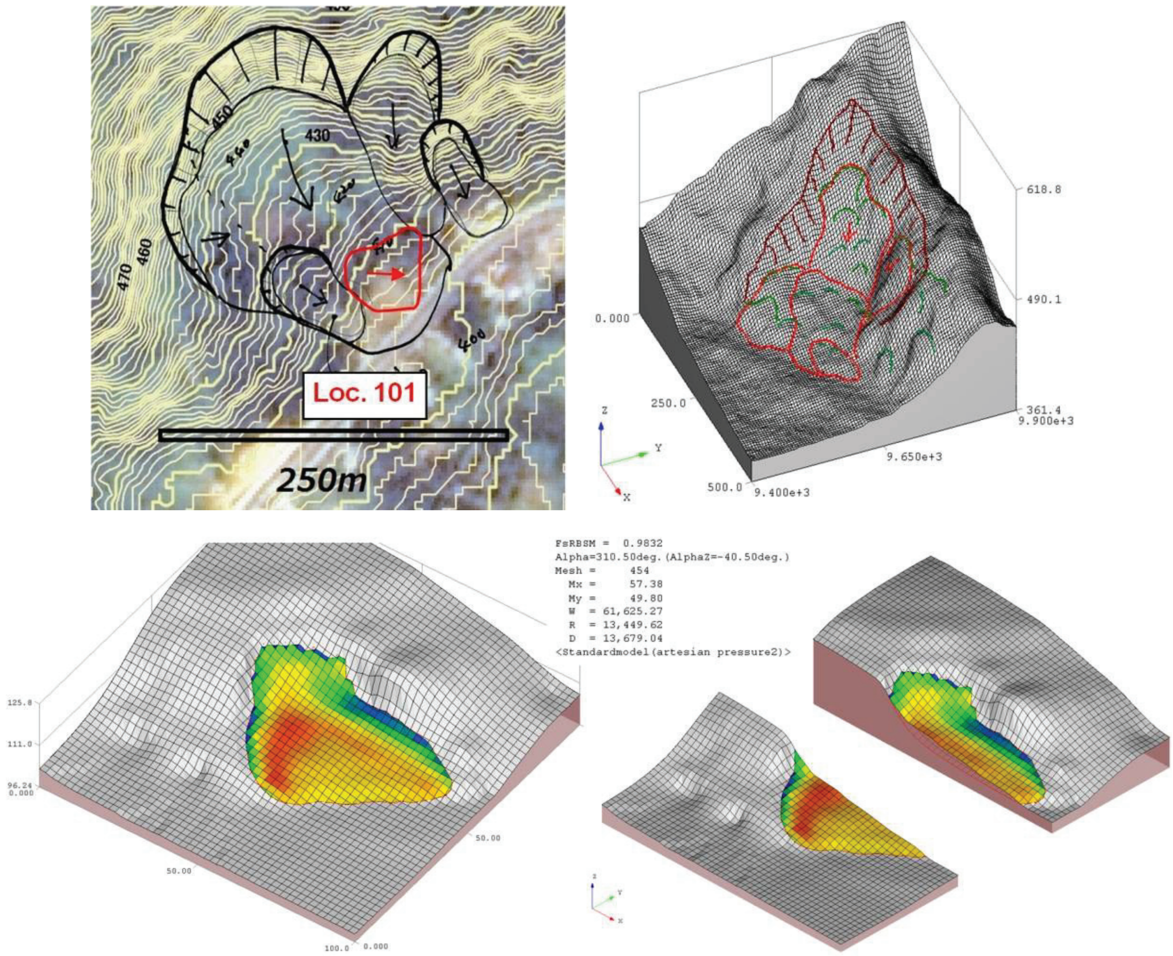


Fig.4. 91 Simulation the slip surface on the contour from W3D data for safety factor evaluation by ADCALC3D

Tab.4. 7 Sensitivity analysis for stable or unstable condition of Ls-Loc.101 using RBSM3D

c', φ' condition (assumed by Ring Shear Test)				Ground water condition	Output			Safety Factor
Fully softened strength		Residual strength						
c'(kPa)	φ'(o)	c'(kPa)	φ'(o)	From Bottom	R (kN)	D (kN)	Direction	Fs
13.2	24.3	6.7	8.3	Full	13,449	13,679	310.50	0.9832
13.2	24.3	6.7	8.3	Void	18,200	12,910	310.32	1.4097

The calculation results in Table 4.7. Fs=1.4097 with no groundwater and Fs=0.9832 if the groundwater is maximum at full condition. This result is very clear. When the groundwater level lower slip surface (Void), the safety factor Fs> 1.0 and the slope is stable. But when the groundwater level full, the safety factor Fs< 1.0 and landslide occurs. Therefore, think about a countermeasures work for against the slip of slope continuing is necessary.

CHAPTER 5. TOTAL MANAGEMENT FLOW OF LANDSLIDE DISASTER RISKS ALONG MAIN ROADS IN TROPICAL MOUNTAIN RANGES – BASED ON RESEARCH ACCOMPLISHMENTS IN CENTRAL VIETNAM –

5.1 Manual of decision making of countermeasures by AHP approaching

This study is considering that total management flow should be set at the fact-finding and mapping stage, the risk evaluation stage, the categorizing stage, and at the management strategy set up the stage. To assist investors (departments in charge of disaster prevention) and the engineer easy make an accurate and effective decision for selection the measures to responding to landslide disaster occur along the artery such as national road, it is necessary to build a comprehensive management system of landslides disaster risks. Especially in Vietnam, where the latest technical knowledge is not always reflected in the event of a landslide disaster outbreak in response procedures of departments in charge of disaster prevention.

The study coordinates various processes from the evaluation of landslide disaster risks on and along roads through simulation of landslide occurrence to proposal of a concept of countermeasures and monitoring into one workflow, to indicate a procedure to be conducted on each phase, and finally to propose a management system. For those purposes, the AHP hazard prediction method of reactivation risks of landslide topography to management classification is applied. The Japanese inspection sheet for landslide AHP score calculation is modified into more user-friendly representations for on-site use. In addition, the landslide scale, spatial relation with a road and gradient of slopes is examined comprehensively to calibrate the landslide risk score. Based on the final landslide risk score, disaster vulnerability is set in descending order from level 1 to level 4, which corresponding to four levels of strategies of road maintenance: 4) countermeasures immediately; 3) tracking tools; 2) patrol incentives; and 1) regular patrols. This management system might be application to all of Southeast Asia as a humid tropical zone.

5.1.1 Introduction

Landslide disasters are an extremely complicated topic related to construction and maintenance management of the backbone of a nation: its main roads and railroads. Landslide occurrence might abruptly cut off lifelines supporting the basis of the social livelihood and economy for many people, and even cause loss of life and property. Mountain ranges in Vietnam are characterized by fragile natural conditions of strongly weathered lithology, steep topography, and heavy annual rainfall that can be as much as thousands of millimeter. Recent areal development has been markedly enhancing the frequency and potential of landslide disasters (Tien et al., 2016). The government of Vietnam has cast landslide disaster reduction as a national objective, and has devised various countermeasures (Fig. 5.1).

Science and technology are always sought for their contributions to slope disaster reduction. This study was compiled to propose a concept of comprehensive slope disaster risk management for mountain ranges in Vietnam as an example. The concept is based on heuristic knowledge of science and technology accumulated to date, such as comprehension and evaluation of disaster risks, disaster experiences, and countermeasures and their effects. Various technology guidelines related to slope disaster prevention have been proposed in various countries for several decades, represented by the technical guidelines for landslide prevention by the US Transportation and Road Research Board (Varnes, D. J., 1978) and by the Ministry of Construction of Japan. Landslide science itself is also progressing. For example, "Landslides: Journal of the International Consortium on Landslides" (Eds. by Sassa et al.) published by the International Consortium on Landslides (ICL) has presented over 100 reports every year since its foundation in 2004. This situation suggests that technology guidelines of Japan or the United States have already gone out of date. Simultaneously, the time has come to establish "novel comprehensive technology guidelines" using knowledge of landslide science which has been greatly extended and enhanced. The Institute of Transport Science and Technology of Vietnam (ITST) has newly prepared guidelines for surveillance study and evaluation of landslide disasters as one accomplishment of the SATREPS project (ITST/JICA/JST/ICL, 2016). Today, mainline networks have grown and spread rapidly throughout economically developing countries of Southeast Asia as well as Vietnam. This report presents a discussion of a scheme of survey and evaluation that contributes to mitigation of slope disaster risks accompanying development to the greatest extent possible in an economically developing country such as Vietnam using cutting-edge knowledge and methods. This report also proposes a concept of comprehensive landslide disaster risk management that is applicable to road systems and railway networks.

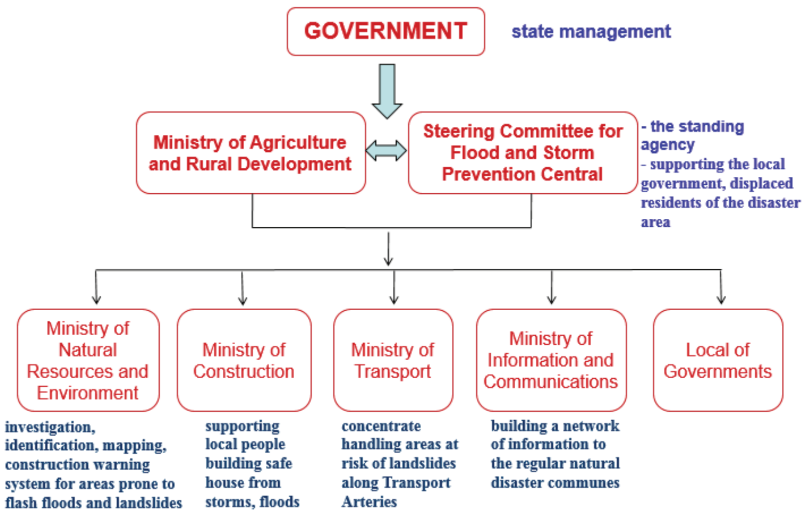


Fig.5. 1 Vietnam's National strategy for natural disaster prevention, response and mitigation to 2020

5.1.2 Methods for Comprehensive Management of Landslide Disaster Risks

Recent successful studies in Vietnam include research on landslide topography distribution, actual occurrence conditions of landslide disasters, effects on landslide occurrence of topography, lithology, and weathering structure, and evaluation of landslide occurrence risks using multiple approaches (e.g., Luong et al., 2016, Tien et al., 2015, 2016a, b, Dung et al., 2016). This situation is introduced in the special issue of "Chikei", the Transactions Japanese Geomorphological Union (Vol. 37, No. 1, 2016). Nevertheless, the latest technical knowledge is not always reflected in the event of a landslide disaster outbreak in response procedures of departments in charge of disaster prevention (Dung et al., 2016). The previously described Guidelines for Slope Disaster Management (2016) submitted to the Department of Transport Infrastructure of Vietnam neither explains how to use these Guidelines on site along the main lines nor indicates workflow from risk evaluation of a landslide to the management concept. This article accordingly aims to coordinate various processes from evaluation of landslide disaster risks on and along roads through simulation of landslide occurrence to proposal of a concept of countermeasures and monitoring into one workflow, to indicate a procedure to be conducted on each phase, and finally to propose a management system.

For those purposes, a series of flows from land classification on roadside slopes is organized for evaluation and management classification. This classification of flows is conducted by mapping, aerial photograph interpretation, and field survey techniques that have been used by the authors and colleagues, followed by the AHP hazard prediction method of reactivation risks of landslide topography (Miyagi et al., 2006, Hamasaki et al., 2010, Tien et al., 2016, Luong et al., 2016) revised into more user-friendly representations for on-site use. Furthermore, a procedure is planned by which each landslide unit is classified into four levels: 4, immediate countermeasures; 3, instrumental monitoring; 2, preferential patrol; and 1, ordinary patrol. The reactivation risk of a specified landslide unit, the landslide scale, and spatial relation with a road, etc. is examined comprehensively.

5.1.3 Proposed Method

Fig. 5.2 portrays the flow of strategies for the selection of maintenance and management methods of the previously described four levels. This flow, work sequence, and thresholds were determined by trial and error through discussion in the SATREPS team of Japan and Vietnam. First, an arbitrary point is set on the center line of a road. Then a reference range of a square $2R$ on a side is set with the previously described point as the center. R is determined as 300 m considering the average scale of landslide topography in the mapping result conducted in central Vietnam, the interval of road distance marks, and the ease of field survey. The reference range is set to the target area of this study. The flow begins with finding the landslide topography (block) in a reference range of a square $2R$ on a side by aerial photograph interpretation and a field survey. The workflow of the field survey and evaluation is divided into the following steps.

1) It is important first to determine whether a landslide is located in this target area by aerial photograph, road patrol, etc. When there is no landslide in this range, any action to this target area is judged as "Not Necessary." Otherwise, if there are subjects for examination, such as a landslide, the process proceeds to judgment *A of the risk score (Fig. 5.3).

2) Fig. 5.3 presents the flow of the risk score (RS, *A). First, if evident landslide

phenomena (cracks and displacements) are recognized on site, then the spatial relationship between the landslide and the road is crucially important. The spatial relation of a landslide is as depicted in Fig. 5.4. When a landslide passes immediately above a road or envelops a road, its occurrence might cause excessive damage over the road. Such a case presents a dangerous spatial relation so that the landslide is located at a position of extremely high impact. Consequently, this case is classified as high risk (H) and RS = 100. Next, even when there is no landslide on a slope above a road, if a landslide head or its part cut the road, then the road might collapse. Such a landslide when such conditions exist is classified as presenting moderate risk (M) and RS = 90. Otherwise, when a landslide range is located on a slope under the road, expansion of a landslide might result in the collapse of a road shoulder in the future. However, because this case does not present any pressing danger, this landslide is classified as low risk (L) and RS = 70–80.

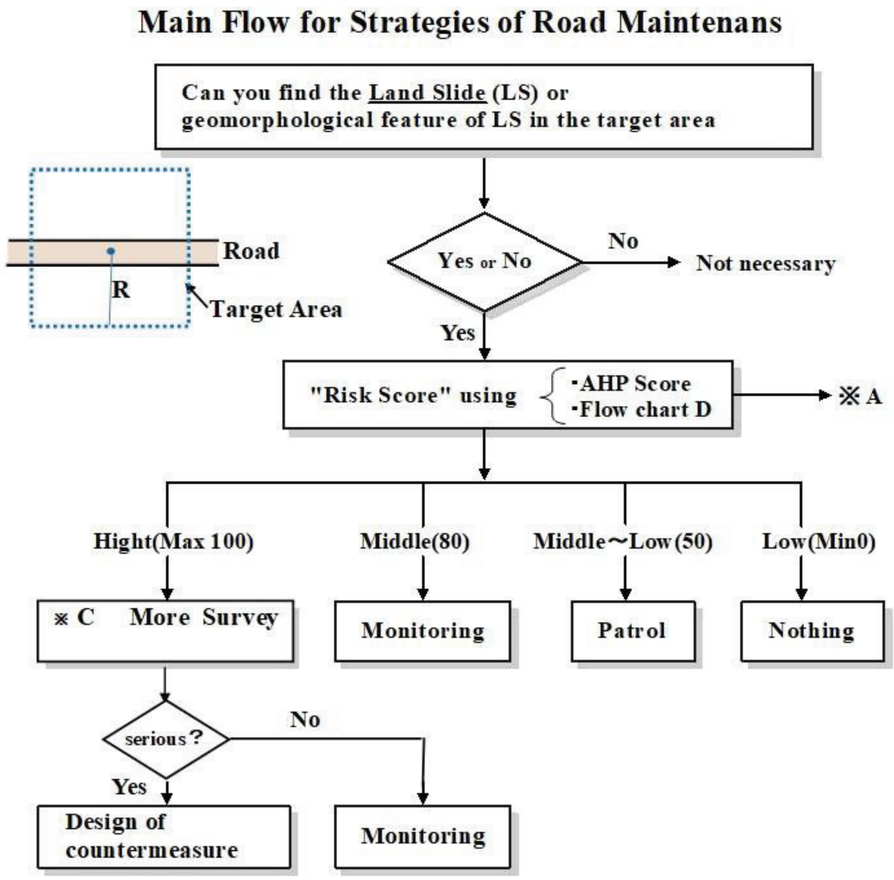


Fig.5. 2 Main flowcharts for strategies for road maintenance

3) Next, in Fig. 5.3 again, in the case in which no evident landslide phenomenon is apparent for the road by on-site inspection, landslide judgment by AHP using aerial photograph plays an important role. The AHP risk judgment method by aerial photograph is described in detail by Miyagi et al. (2004). The procedure presented in Fig. 5.6 created by a Japanese examination team has produced many accomplishments (e.g., SATREPS in Croatia and study by Luong in Vietnam). Additionally, its modified version is in use in Hokkaido,

Japan for landslide risk judgment (Ishimaru et al., 2010). Luong et al. (2016) omitted check items with low weight among these inspection items and restructured a simplified inspection sheet (Fig. 5.7). The performance of this new AHP procedure was verified in the case of the Ho Chi Minh (HCM) Route. Results show that little difference exists in AHP scores by judgments with the new system, so that the new system is fully functioning.

The AHP scores are in the range of 0–100 because it is regarded as important to evaluate a risk score with weight varied by the spatial relation with a road (α), the scale (β), the gradient (γ), etc., so that risk score RS is defined as RS = AHP Score × $\alpha \times \beta \times \gamma$ as presented in Fig. 5.2. The thresholds of α, β, and γ are portrayed in Fig. 5.5. Position α is determined using the previously described relation of Fig. 5.4, as 1.0 in cases of H, and 0.9 and 0.8, respectively, in cases of M and L. The scale of a landslide β is set to 1.0 for the Large class of an area of 104 m2 or larger, 0.9 for the Medium class of 104 – 102 m2, and 0.8 for the Small class of 102 m2 or smaller. The gradient γ is set to 1.0 when the slope gradient of a landslide exceeds 30°, to 0.9 when the slope gradient is 10–30°, and to 0.8 when the slope gradient is 10° or less.

4) The evaluated risk score result is given as the judgment of the final stage of Fig. 5.2: if the score is 50 or less, then no action is taken. This is defined as Level 1. If the score is 50–70, then preferential patrol is conducted (Level 2). If the score is 70–80, then simple monitoring is conducted using physical instruments, such as an extensometer and GPS (Level 3). If the score is 80 or greater, then advanced investigation (more survey) is conducted as follows (Level 4). The advanced investigation is a detailed analysis with a detailed topographical survey by a UAV surrounding a landslide, field survey, and drilling survey or soil texture sampling test if necessary. Regarding slip planes, the landslide structure is

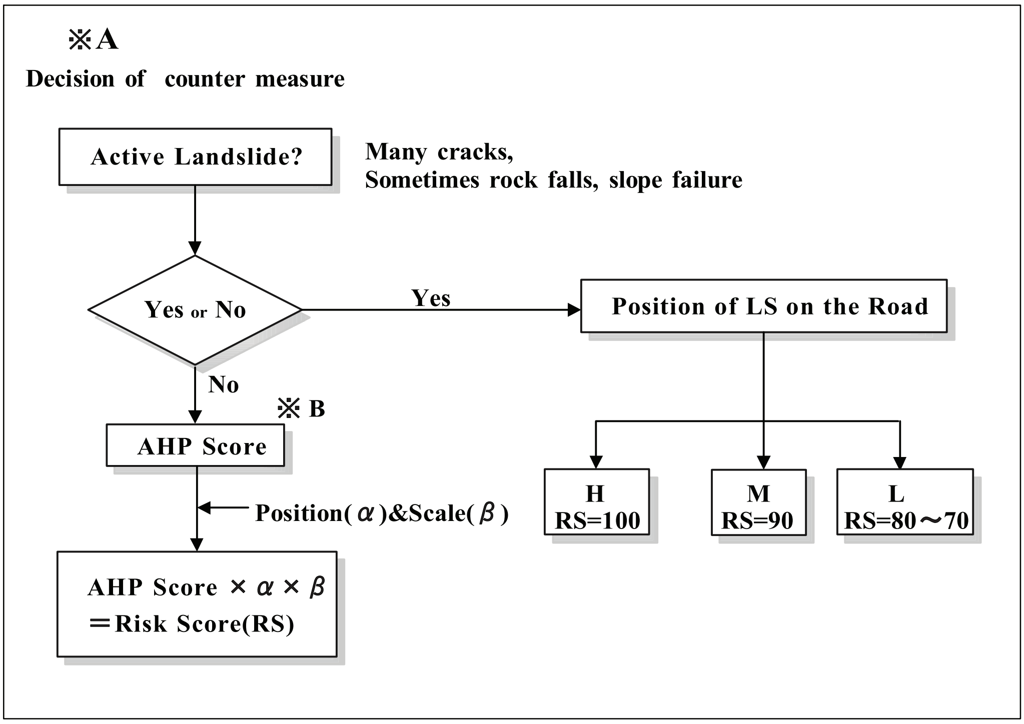


Fig.5. 3 Main flowcharts for making risk scores

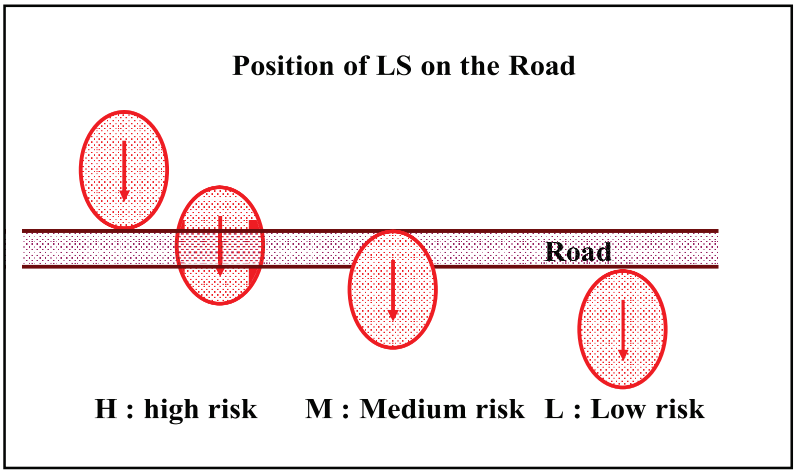


Fig.5. 4 Schematic location diagram of landslide and road

α : Ratio of Position (Fig.3)

Position H = 1.0

Position M = 0.9

Position L = 0.8

β : Ratio of Scale

Large($A \geqq 10^4$) = 1.0

Medium = 0.9

Small($A \leqq 10^2$) = 0.8

γ : Ratio of Gradient

Steep (≧30deg) = 1.0

Moderate = 0.9

Gentle (≦10deg) = 0.8

Fig.5. 5 Integration ratio of position and scale and gradient of slope for risk score

assumed reasonably with estimation of a slip surface contour by reference to algorithms by Hamasaki (2016) for example. The slip characteristics are revealed through stability analysis. Then “landslide countermeasure work” is selected when a landslide is expected to cause a severe result, for example, to slip at a stretch and destroy road functions at one burst, and otherwise “instrumental observation: monitoring” is selected.

The configurations of a slip surface that might cause a severe result include a landslide with high translation property and a steep gradient for example. However, it is less severe when a resistance zone is observable as an uplifting at the toe of a rotational landslide is apparent and the slip velocity is expected to be low. Evaluation of these details is left as a subject for future study.

5.1.4. Verification of the Proposed Method

This study proposes a workflow that targets main lines such as roads and railroads. The effectiveness of this proposal is not confirmed until this proposal is actually implemented by on-site engineers in charge and is verified to engender reduction of slope disasters. The proposal of a flow has the meaning of indicating a path. However, each step of the flow is requested to bear certain technical sources or a scientific basis to secure the flow effectiveness. Accordingly, this chapter demonstrates the basis of effectiveness by presenting study examples in Vietnam at each step.

1) Fact-finding stage

Slope disasters along the main lines in Vietnam have been investigated. Countermeasures have been implemented by MOT in each event so that fundamental data are fully available. However, the status data of potential slope disaster factors by aerial photograph interpretation and field survey about the HCM route has been compiled recently by surveillance studies in cooperation of Tien, Luong, Dung, and Japanese researchers through the SATREPS Project. As described in the preceding chapter, mapping can be conducted only on the Vietnam side at present.

2) Risk evaluation stage and Categorization stage

Mapping has improved the accuracy of aerial photograph interpretation. Furthermore, it has enabled micro topographic interpretation. Moreover, a procedure of comprehending the three-dimensional structure of a landslide has been developed (Hamasaki, 2016). Evaluation of risks and the latency of landslide occurrence have been explained in multiple reports of studies by Luong et al. and Tien et al,. Risk level is classifiable according to an AHP score, as described above. Disaster vulnerability is set in descending order from Level 1 to Level 4.

3) Management strategy set up stage

Stability analysis to each target landslide is recommended for landslides of risk levels 3 and 4. This analysis requires information related to detailed topography, slip surfaces, lithology, and soil properties. Such basic information with accuracy necessary for analysis has not been fully accumulated in Vietnam. However, soil constant data have been collected through this project based on comprehension of landslide symptoms of a wide area by ALOS W3D Data (5 m grid DSM) and measurement of retained strength in the study area of the project and a region along NH 7 (Dung et al., 2017). Geological information and topographic maps have accuracy of a certain level. Accordingly, it is almost always possible to compute a safety factor using analysis simulation software (e.g. Adcalc 3DTM; Green Technos Co. Ltd.). In addition, prototyping of a landslide topography classification map using contour information created from ALOS W3D Data is conducted (Dung et al., 2016).

4) Comprehensive management of experimental landslide disaster risks

It is necessary to conduct a specific trial. Multiple landslide stability analysis cases have been accumulated to date (Dung et al., 2014). It is necessary to accumulate stability analysis cases according to the level of landslide risk.

5.2 Conclusion

This study presents a proposal of a “comprehensive management flow of landslide

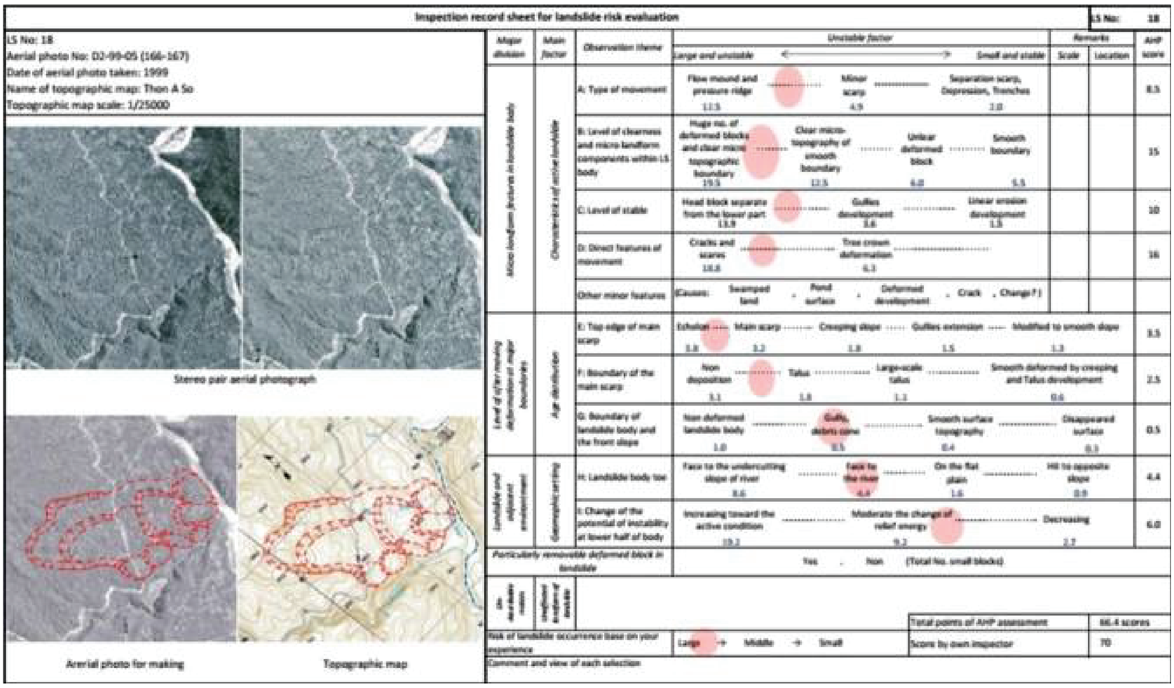


Fig.5. 6 Japanese Inspection Sheet for Landslide AHP Score Calculation (Miyagi 2003)

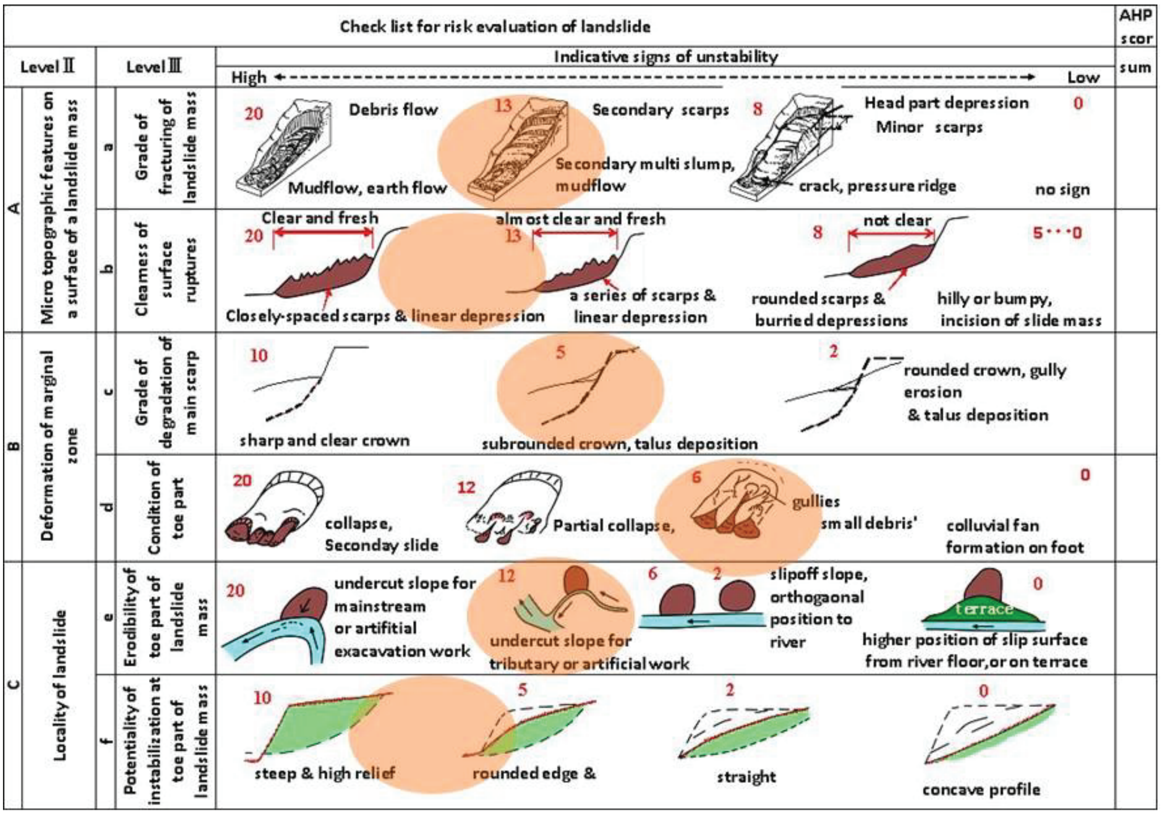


Fig.5. 7 New Inspection Sheet for Landslide AHP Score Calculation

disaster risks" that is useful for reduction of slope disasters taking place along main roads, with the final objective of comprehensive application to all of Southeast Asia as a humid tropical zone. The SATREPS project has been conducted particularly addressing a national road constructed in the mountain range in central Vietnam. The project involves widely various studies including recognition of landslide disasters, accumulation of various information related to topography, lithology, and soil property, evaluation of the reactivation risk of a large-scale landslide, and the landslide occurrence potential of whole slopes. This study is constructed based on these accomplishments. It is considered that comprehensive management flow should be set at the fact-finding stage, the risk evaluation stage, the categorizing stage, and at the management strategy set up the stage.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

This research demonstrated the interest of combining the stages as (1) identify for landslide, (2) assessment for recognition the actual landslide and the slip mechanism, (3) evaluation for stabilizing the target landslide and (4) decision making for landslides countermeasures were applied to build a Framework Total Management of Landslide Disaster Risks along main roads in tropical mountain ranges. This system might be effective applied to Vietnam and also to all of Southeast Asia as a humid tropical zone. The Analytic Hierarchy Process (AHP) hazard prediction method by Miyagi et al. (2004), Miyagi et al., (2006), Hamasaki et al., (2010), Tien et al., (2016), Luong et al., (2016) might be applied to evaluate of risk score of reactivation risks of landslide topography. In addition, the criteria such as the spatial relation of landslide with a road (α), the scale of landslides (β), and the gradient (γ) of slope are very important characteristics of the small and medium scale landslides along main roads in the humid tropical zone like Vietnam have been considered to calibrate the landslide risk score. Based on the final landslide risk score, disaster vulnerability is set in descending order from level 1 to level 4, which corresponding to four levels of strategies of road maintenance: 4) countermeasures immediately; 3) tracking tools; 2) patrol incentives, and 1) regular patrols. According to their levels, no action is taken for Level 1, but needs a preferential patrol for Level 2. Then, a simple monitoring is conducted using physical instruments, such as an extensometer and GPS for Level 3. For the Level 4, some advanced investigation (more survey) must be conducted. The advanced investigation is a detailed analysis with a detailed topographical survey by a UAV surrounds a landslide, field survey, and drilling survey or soil texture sampling test if necessary. Regarding slip planes, the landslide structure is assumed reasonably with the estimation of a slip surface contour by reference to the algorithms by Hamasaki (2016) for example. The slip characteristics are revealed through stability analysis. Then "landslide countermeasure work" is selected when a landslide is expected to cause a severe result, for example, to slip at a stretch and destroy road functions at one burst, and otherwise "instrumental observation: monitoring" is selected. This research indicated how a combination of methods is a relevant method of identifying real slip surface by field investigation techniques, and likes to clarify the actual landslide and the slip surface mechanism. The main objectives of the research were:

- to develop methods of field survey, risk assessment, and classification consistent with the characteristics of landslides in the humid tropical country like Vietnam;

- to clarify the relation of potential landslide risk with geological structure, level of weathering and the strength of the rocks in the humid tropical zone and build the method of determining the real slip surface, method of determining the mechanical properties of the rock on the slip surface to understand the mechanism of sliding;

- to used the collected data for simulation the phenomenon, assess the safety factor and select the appropriate response solution.

The methods have been developed based on the history data of landslides occur along main roads in the past and by a series of field investigations in Central of Vietnam in the period from 2010 to 2016. The study sites are including a typical landslide on NH6 located at 95 km far from the starting point of NH6 at Hanoi capital, about 350km long along HCMR corridors in the Central, and about 70km long of NH7 in Nghe An province (section from Muong Xen to Son Ha).

Considering the vulnerability of natural disasters and the status of landslide in Vietnam as well as proposed the objectives, subjects and methodology for this research are presented in Chapter 1. Title "Total Management of Landslide Disaster Risks along Main Roads in Tropical Mountain Ranges" and main structure of this dissertation is also mentioned in this chapter.

The status of landslides disaster along Transport Arteries, the key causes of landslide and current status of study on landslides in Vietnam are mentioned in Chapter 2. Vietnam is one of the countries deeply affected by global climate changing. The landslides phenomenon flourished with growing scale and the extent of damage is increasing and threatening the public safety. The high and very high risk of landslide concentrated in the Northern mountainous region, the Central and Tay Nguyen region, but it is especially severe and concentrates in the Central. The key causes by characteristics of monsoon climate, geology, topography and geomorphology features in the humid tropical region accompanied by the construction of new roads and urbanization.

Chapters 3 present the current situation and strategy for response, mitigation and prevention of landslide disasters in Vietnam. The Vietnam government has overall strategies to deal with natural disasters as well as landslides. However, the results of response, mitigation and prevention of landslides are still limited. The root causes are lack of experts with deep experience in landslide field, technological processes, guidelines for the survey and design of landslide prevention are still in the process of building and completing. There are much limited in the current manuals for classification, survey, design, stability evaluation and choosing a solution for mitigation and prevention of landslides. Have not been established a workflow of strategies for the selection of maintenance and management methods of mitigation and prevention of landslides, it can help engineers how to choose an effective solution, and road management agencies easier making a decision.

The main studies of the dissertation are present in Chapter 4 and Chapter 5.

In the first section of Chapter 4 is a landslide topography mapping technique using ALOS W3D data. A topographic map of about 10 km wide and about 70 km long centering on NH7 was created and more than 1000 landslide areas were identified (Dung et al, 2016) by using this computed topographic map using the ALOS W3D Data, contour lines were read visually in a range of 3–4 km wide, centering on the national highway. Recognizable landslides were extracted and visualized. Although only landslides of a width not less than about 100 m were extracted, the landslides extracted has exceeded 1,500. It is noteworthy that the embedded structure is also included. The identified area includes various types of slopes. The topography by fluvial processes such as those of terrace surfaces and alluvial cones, and non-sliding slopes such as those of ridge slopes and valley slopes, were classified and mapped together after proper judgment. These landform classification data will to be included in a database by GIS. Results suggest that the distribution of landslide topography corresponds extremely well to the geography and geology. The distribution of landslide topography has a high density in the western part (about 50 places within 10 km of road extension), and low in the east. Furthermore, landslide topography is observed only slightly in the tropical tower karst region of limestone. Geologic phenomena corresponding to this are as follows: sandstone and mudstone deposited from the Ordovician to Silurian period in the first half of the Paleozoic were subsequently folded and metamorphosed to clay stone; the geological feature of steep slopes and development of numerous joint and fault structures was produced; and an extremely vulnerable geologic structure was produced by weathering peculiar to the tropical zone, such as generation of a weathered layer following emergence in the end of the Paleozoic, and red weathering advanced through the Quaternary. Development of dissection following the formation of the drainage network of a river specified a slope scale and an average gradient. In the range for interpretation, the dissection in the western part is as deep as 500 m. Its slope is generally 30 deg or more, sometimes as much as 50 deg. Landslide fracture broke out on many slopes when such a steep and severely weathered rocks got a dip slope structure. However, the relative height and gradient are reduced greatly, even on the identical geological conditions in the central part of the target area, so that the distribution density of landslide topography seems to show a great decline corresponding to this. Completion of the GIS database is expected to facilitate more accurate comprehension of such a distribution status.

Quite recently, ALOS W3D Data used for creation of a topographic map and interpretation of landslide topography in this study were released. It can easy to purchase now. This study might therefore be the first to use these data for the preparation of a landslide topography distribution map of the world. Results demonstrate that information equally matched with verification by field survey can be prepared.

The second section of Chapter 4 details the methodology to develop a technique of field survey, classification consistent with the characteristics of landslides in the humid tropical zone. Result of studies shows that almost small to medium-scale landslides along HCMR were mainly caused by geological structures and weathering and by earth cuts made during road construction.

Along 150km long from A Luoi to Thanh My of HCMR, the geological features of the northern part is mainly made up from sedimentary rocks such as mudstone, siltstone, sandstone, conglomerate, limestone, marl and shale from the Paleozoic era, metamorphic rock consisting largely of quartz schist and mica schist from the Paleozoic era, as well as granite. The distribution of these shows a tendency for arrangement in a northwest-southeasterly direction parallel to HCMR. Paleozoic and Mesozoic granite is widespread across the study area as a whole, and metamorphic rock which becomes hard Hornfels can be found in this area (Abe et al., 2014). Based on the classification of Varnes (1978) for landslide movement types, they can divide into 6 types. In addition to the classifications of translational rock slide, rotational slide, and rock fall, three landslide classifications were added such as translational wedge type slide where a moving mass slides in a triangular form, translational shallow debris slide where debris of thickness under 1 m slide down the bedrock, and gully type slide and flow where an arc-shaped sliding mass originating at the upper area of a slope slide down the slope surface, and the morphology resembles an erosion gully. Therein, 40% of landslides in the areas of schist is the classification of gully type slide and flows, translational rock slides occupy approximately 70% of landslides in the area of Mesozoic sedimentary rocks. Rotational slide and translational shallow debris slide are common in the area of Paleozoic shale and sedimentary rocks. Gully type slide and flow are next commons. Approximately 60% of landslides in the area of hornfels distribution are rock fall. Granite/gneiss has a small distribution and has few examples of landslides, but various types of landslides occur including translational wedge type slide.

Section from Thanh My to Kham Duc appears the surface landslides, shallow landslides and sometimes are deep landslides. The wedge type of landslides was combined by the geological structure and weathering structure. Surface landslides and shallow landslides usually are small sizes of landslides, but the number is much more. Sometimes, some small of landslides combined together to bigger landslide. An important feature is surface landslides and shallow landslides mostly distribution along the road, that were difficult recognition from aerial photographic interpretation, but emergency and dangerous, therefore it is a problem to control and mitigate it. The Kham Duc town belongs to the Quaternary zone, geological structures are usually flat. Geological including lake deposits with extremely weak layers such as organic rich, peat and clayey layers, volcanic rocks with intruded basalt consolidate hard and heavy rock. The lake deposits are black, reddish brown, but the weathering level is not so deep. The boundary of the volcano and lake deposits is black deeply weathered material, with many holes because of the lava gas. Lake sediments are deeply weathered and changed in clayey materials. Landslides occur as rotational slides along river side slopes, with a complex of small to surface landslides and soil creeps.

In this chapter, the Landslide Field Inspection Sheet (LFIS) has been established in detail of the field investigation of landslides in the humid tropical zone. The 33 small to medium-scale landslides along HCMR near Prao area were detail investigated using LFIS. The results indicate that have a relation to the geological structure level of weathering and the strength of the rocks. The number of landslides occurred concentrate on the heavy and soft weathering geology area, up to 49% in the heavy and 34% in the soft weathering geology area. In the deep weathering geology area was occupied 14% and only 3% of number landslides were observed in the un-weathering area (fresh rocks). The number of landslides based on geology and its percentage shows that gully type and slide is the most common type in the areas of schist. Topple type is common in the area of sandstone and schist. Granite/gneiss, sandstone (Laminate) and mylonite have a small distribution and have few examples of landslides. That is to say the weathering characteristics of rock and the style of the slope movement seemed to vary depending on the soil characteristics (era and rock type).

Result of field investigation along NH7 in the geology area by sedimentary rocks of the Mesozoic to the Paleozoic, and limestone of the Mesozoic, forming the landscape of tropical tower karst. Landslides are high risk of reactive potential and tend to push the NH7 moving down to the Ca River.

The third section of Chapter 4 have been clarified the residual strength characteristics of weathered rock in Central Vietnam. The results from the study showed can deduce the real slip surface of the small scale landslide by field investigation and site experiments. Slip surface usually appears in a thin layer of geology, which is very weak strength, heavily weathered, easily swollen and reduced the strength by saturating (e.g. weathered mudstone and cohesive soil). This layer was sandwiched between the upper layers of weathered rocks and the underlying fresh rock layers. It is often the case that 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 and less hardness points at the around the slip surfaces. The mineral composition and physical characteristics differ depending on the geologic age, degrees of weathering and that their residual strength changes similarly. Especially, younger strata has a smaller angle of residual shearing resistance. The kaolin appears at heavily weathered rock instead of illite only contained in the fresh rock. High-plasticity clays with high clay content, high plasticity index, and high liquid limit have a smaller angle of residual shearing resistance and that the soils of young geologic age contain swellable clay minerals and produce high-plasticity clays. Countermeasure work in Vietnam should be planned at each slope after the elucidation of their dynamic respective characteristics.

Evaluation the stabilizing of the target landslide using the slip surface deduce from at field investigation and on the contour from W3D data, and the result of soil tested have been carried at last of this chapter. Result showed potential of landslide re-occurs is high remaining, although some countermeasure work have been installed. In addition, residual strength of soil on the slope is a very important parameter to evaluate the potential of landslide reactivation. The sensitivity of the safety factor of slope varies corresponding to the actual condition of groundwater before and after the rainy season in Central Vietnam.

Finally, a New Inspection Sheet for Landslide AHP Score Calculation and a new Framework Total Management of Landslide Disaster Risks along main roads in tropical mountain ranges were proposed in Chapter 5. The New Inspection Sheet for Landslide AHP Score Calculation easy for user and consistent with the characteristics of landslides in the humid tropical country like Vietnam. The Framework Total Management of Landslide Disaster Risks have considered on characteristics of the landslide along transport arteries and procedure of landslide management in Vietnam. It is considered that comprehensive management flow should be set at the fact-finding stage, the risk evaluation stage, the categorizing stage, and in the management strategy set up the stage. Therefore, that might be effective applied to Vietnam as well as to all humid tropical zones of Southeast Asia.

For future study, base on the outcome of this research and considering the stage of development of landslide risk research, the following future work in continuation of this research is suggest as below:

- Research to update and supplement the manuals on survey, stability evaluation and design landslide countermeasure work;

- Greater study and discussion are needed to produce a high-quality landslide topography mapping along transport arteries using ALOS W3D data;

- Continuing research to develop completing the method of identifying real slip surface by field investigation technique or combine with other techniques;

- The Landslide Field Inspection Sheet and the New Inspection Sheet for Landslide AHP Score Calculation should be discussed much more to become useful documents for survey and risk evaluation potential of landslide;

- Each stage and criteria in the Framework Total Management of Landslide Disaster Risks should be discussed much more to establish a landslide prevention policy suited to characteristics of Vietnamese national land.

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