AN ANALYSIS OF CAUSES TO DAMAGES FOR RURAL ROADS IN THE NORTHERN MOUNTAIN REGION OF VIETNAM AND AN ORIENTATION TO SOLUTIONS

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***Summary**: This paper is to conduct analyses of root causes to typical damages and losses to rural roads in the Northern mountain region of Vietnam; on such basis, to recommend guidance to solutions. The results from this study have shown that there are many different types of damage occurred on different components of rural roads. These damages are often associated with defects in various implementing phases including: rural road planning, design, construction and operation and maintenance. The findings in this study can be used as a basis for developing countermeasures to enhance the sustainability of rural roads in the Northern mountain region.*

***Keywords**: Rural road; damages; mountainous region; climate factors.*

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1. Introduction

Rural transport network is a local transport sub-network connected with the national road system to serve agriculture-forestry-aquaculture production and economic-cultural-social exchanges among villages, communes and hamlets. Rural roads are understood to be district-level roads or lower, including district roads, communal roads, village roads and roads to rural farms, production areas. Regarding technical aspects, the district-to-commune adjoining roads and inter-communal roads are generally designed in accordance with technical standards for roads at grade IV, V and VI in line with the standard TCVN 4054-05 (Highway - Specification for Design) [1]. Communal roads are generally designed to be equivalent to roads at grade VI in line with the Standard TCVN 4054-05, and road types A, B, C and D in line with the Standard TCVN 10380-2014 (Rural roads - Specifications for Design) [2].

The development of rural road system in Vietnam is not consistent among regions, areas, of which the Northern mountain region still has a rather poor rural road system. By early 2010, there are approximately 42,411 km rural roads in the overall Northern mountain region including district roads, communal roads, village roads, excluding roads connecting to farms, accounting for 21.66% total length of rural roads nationwide [3]. Regarding coverage, the density of rural roads in the Northern mountain region remains as low as 0.44 km/km^2 compared with 1.16 km/km^2 of Red river delta. By the year of 2011, there are no automobile roads to the communal centers in 7 communes in the region out of totally 149 communes nationwide [3].

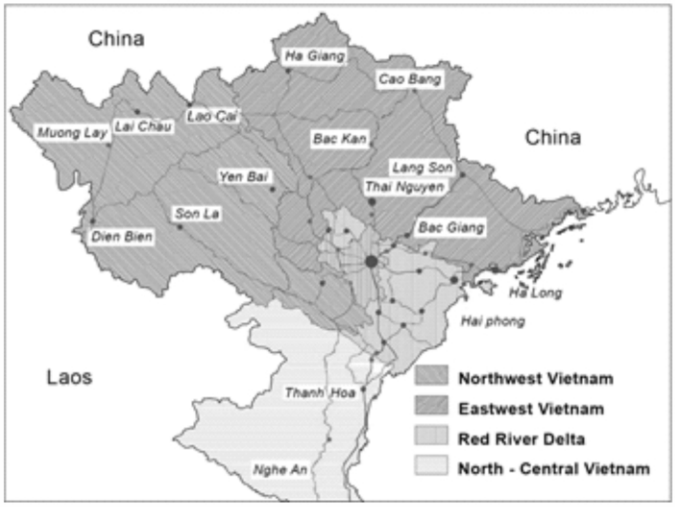

***Figure 1.** Location of Northern mountain region of Vietnam*

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The facts show that the quality of culverts, bridges across district roads, communal roads still remains low and inconsistent. The load bearing capacity of most culverts, bridges on district roads is under the design load of H13-X60, that are rather low for nomal traffic; and that of communal roads is even as low as H8. Furthermore, many rural roads acrossing rivers, streams have only temporary bridges, forts, and over-spill structure. Village roads are narrow and many of them are designed with one lane only.

The rural road network plays a vital role on socio-economic development in mountainous areas such as the Northern mountain region of Vietnam. As shown in Figure 1, the region consists of the two economic areas of the Northwest and Eastwest. The region is characterized by low development, economy dominated by agriculture, highest rate of poverty in the country with 26%, the economic scale of the area contributing only 5,8% GDP to the GDP of the whole country. As regards to the population, ethnic minorities account for 60%, ranking the highest among regions in the country; population density is the second lowest compared to that of other regions, people are living dispersedly. About the terrain, 74% of the area are mountainous and rolling and difficult to connect; weak accessibility to public and social services. The complecate terrain in association with the extreme climate events cause landslides occurring frequently, making a lot of social concerns [4]. With these aforementioned conditions, the development of rural transport infrastructure in the area is very difficult and costly while the economic benefits of the investment is rather limited due to low population density and very long road sections needed to connect communes and villages. Furthermore, the disadvantages of topography and climate factors often make the rural road works in the area unsustainable.

Generally, the road surface in Northern mountain region is of low quality and has not been invested adequatelycompared with other economic regions. In terms of district and communal roads, the percentage of asphalt paved roads and cement concrete paved roads is only about 12.44%, ranked the lowest nationwide. Over 40% district and communal roads are paved with local aggregate materials or macadam. The percentage of unpaved roads ranks top nationwide with 45% district and communal roads of earth pavement structure. In addition, most of the village roads are unpaved roads [3].

The rural roads are slided, thrown away or surface deteriorated, etc., which occurs quite frequently and tends to become more frequent. Despite investment, many rural roads in the Northern mountain region are prone to damage and losses during the operation, failing to reach the design service life and reducing efficiency of works investment and construction. Many causes are attributed to the damage and losses to rural roads, mainly shortcomings from the implementation of steps: planning, design, construction and exploitation of road works. Moreover, climate change accompanied with increased extreme weather events such as big storms, rainfall with strong intensity and duration, more frequent flashfloods, etc. acts as an agent to pose threats to increased damage and losses to rural road system, especially in existing conditions where many rural roads in this region have not been invested and built completely and solidly.

In the context of adverse impacts by climate factors, the identification of historic typical damages to rural roads in Northern mountain region and their causes plays a key role in the recommendations of solutions to mitigate further losses. In Vietnam, there is almost no in-depth research on this issue. Therefore, the objective of this paper is to conduct analyses to find root causes to typical damages and losses to rural roads in Northern mountain region; on such basis, to recommend guidance to solutions.

2. Methodology and research data

To fulfil the objective of the paper, data for the identification of typical damages and causes to damages of rural roads were collected from sources/by methodologies as below:

- Interviewing survey: Consult with local authorities (specialized managerial units on rural roads) to preliminarily identify typical damages of rural roads, causes and relevant issues. The consultations were conducted in provinces of Son La, Hoa Binh, Yen Bai and Ha Giang.

- Questionnaire survey: Due to limited resources and time, the direct consultations were only conducted in few local authorities, several questionnaire surveys and phone interview are carried out to consult rural road infrastructure management agencies at district level in all Northern mountain provinces and 61 districts out of the total have respondences. The questionnaire focuses on typical damage and loss of rural roads. The questionnaire was also designed to get opinions and experiences of the local road managers.

The questionnaire focuses on clarifications of frequency and severity level of each type of damage and loss occurred on rural roads under the district's management scope. The types of damages and losses included in the questionnaire are considered based on consultations with local authorities (mainly in Son La, Hoa Binh

province - and the questionnaire is developed based on consultations and site visits to these two provinces). The questionnaire is also designed to understand causes to each type of road damages and solutions to several damages as well as to collect other information about rural road network. The results of questionnaire survey are used to make a preliminary assessment of the frequency of occurence and severe level of types of rural road damages and lossess as presented in Table 1.

- Site survey: A site survey was conducted after the results of questionnaire survey are documented. The site survey aims to deeply understand typical types of damages and root causes to each type of damages. Site visits were conducted at several rural roads that posed typical damages in Son La, Yen Bai and Ha Giang.

All surveys to collect data were taken from May 2014 to August 2014 at the aforementioned locations.

3. Typical damages and losses

Rural roads are comprised of key items, including carriageway (surface), shoulder, slopes (cut-slope, fill-slope) and drainage items (bridges, culverts, ditches). The mechanism to cause damages to each item is different; therefore it is necessary to analyze causes to damages of each item of road works.

The survey shows that there are various damages to rural roads with different frequencies of occurrence and levels of severity. During the survey, the frequency of occurrence is assessed qualitatively by four levels: 1. Rarely; 2. Occasionally; 3. Ussually; 4. Frequently. Severe level is generally assessed by the frequency of occurrence and losses caused by each type of damage including direct and indirect losses. The summary of types of damages and losses for rural roads and preliminary assessment on the frequency of occurrence and severe level of each damage type are shown in Table 1.

The survey findings in Table 1 show that the key, remarkable types of damages and losses for road surface can be categorized in two groups - (i) polished aggregate, depressions, corrugations and shoving, potholes, cracking on bituminous, macadam and aggregate road surfaces; and (ii) unpaved road surface is become muddy and in rutting due to wheel's tracks. The damages and losses to be concerned about for road slopes include (i) failure of cut-slopes; and (ii) failure of fill-slopes on steep slopes (including natural slopes). Regarding drainage works, the key, notable damages and losses include (i) bridges, culverts to be blocked, deposited; (ii) side ditches to be deposited or damaged; and (iii) bridges, culverts (including road bases) to be thrown away by flashfloods. The root causes to aforementioned damages will be analyzed in further sections of this paper.

4. Analysis of causes to damages and losses

Generally, any damage occurred is attributed to defects in one or more steps, that is, planning, design, construction and operation and maintenance of works. The defects are not limited to non-compliance with applicable regulations for each step but understood in a wider context as results of the implementation of each step that fails to meet actual conditions once the road works come into operation. Below are root causes to damages and losses for rural roads in the Northern mountain region as described in Section 3.

4.1 Causes to damages and losses for road surface

4.1.1 Depressions, corrugations and shoving, potholes, cracking on bituminous, macadam and aggregate road surfaces

As presented in Figure 2, the overloading vehicles are the most typical cause to this type of damage. Although many rural roads are designed for light-weight vehicles only (for example, rural roads at grade A is designed for axle loads of 6T/axle; rural roads at grade for light-weight motorized vehicles and simple vehicles [2]); however, as a shortcoming, there is no specific regulations to control vehicles' loads on roads except setting out sign posts to limit loads at several bridges on route. The inconsistency between the design loads and actual loads is the first cause to damages of road surfaces to be found.

The second cause to damages of road surfaces is inadequate drainage system which leads to the water runoff flows freely on the road surface and spill up over the drainage system (Figure 3). The penetration of surface water on roads reduces the strength of road bases and pavement structural material layers, which deteriorate road surfaces when vehicles pass through. Site observations show that on the same road, the locations where road surfaces are frequently wet will be those at which damages of road surfaces occur first.

One of the reasons to the poor condition of the curent drainage system all over the local roads as found is due to lack of regular maintenance. Culverts, ditches are grenerally congested with full of mud, plants… leading inefficient operations. In addition, improper design was also leading to long lasting, moisture saturation roadbed and surfaces. On several roads, water runoff in ditches overflows on road surface upon heavy rain. Most of the ditches are unpaved ones causing severe erosion in the ditches' base.

Table 1. *Preliminary assessment of the frequency of occurence and severe level of types of damages and lossess to rural roads*

Types of damages	Frequency of occurrence	Severe level	Notes
I. Pavement			
1. Polished aggregate, depressions, corrugations and shoving, potholes, cracking on bituminous pavement.	Ussually	Relatively severe	Bituminous pavement is only applied to district roads, and few communal roads are asphalt-paved roads
2. Polished aggregate, depressions, corrugations and shoving, potholes, cracking on macadam and aggregate pavement.	Ussually	Relatively severe	
3. Eroding, washing away fine granular materials (due to rainfall) on macadam and aggregate road surface	Ussually	Less severe→ Relatively severe	
4. Curling/warping, cracking, break, settlement on cement concrete pavement.	Occasionally	Less severe	Cement concrete pavement accounts for minor percentage compared with other types of road surface
5. Rutting on earth road surface and similar unpaved road surface due to wheel's tracks	Frequently	Less severe→ Relatively severe	Earth road surface (unpaved surface) accounts for a major percentage
6. Bleeding on bituminous pavement due to high temperature	Rarely	Less severe	
II. Roadbed and slopes			
1. Cut-slope is slided.	Occasionally→ Ussually	Relatively severe	
2. Fill-slope on steep slopes (including natural slopes) is slided.	Ussually	Relatively severe→ Very severe	Rehabilitation for a damage generally requires major work due to necessity of supporting structures (retaining wall) or reclamation of location of routes with damages
3. Slope surface is slided and eroded.	Rarely	Less severe	
4. Filled road based on soft ground is settled.	Rarely→ Occasionally	Relatively severe→ Very severe	This type of damage is less affected by climatic conditions.
5. Filled road base along rivers, streams is slided and eroded due to the flows.	Rarely→ Occasionally	Less severe	
III. Drainage works			
1. Connecting works of upstream, downstream culverts are slided and eroded.	Occasionally	Less severe	
2. Culvert structures are settled, broken.	Occasionally	Less severe	
3. Bridges, culverts are blocked due to mud, waste, trees.	Frequently	Relatively severe	
4. Side ditches are deposited or damaged, leading to runoffs over road surface.	Frequently	Relatively severe	
5. Side ditches are slided and eroded.	Rarely	Insevere	
6. Bridges, culverts (including road base) are washed away due to flashfloods.	Occasionally	Relatively severe→ Very severe	
7. Spans of bridges, culverts fail to meet drainage requirements.	Occasionally	Less severe	

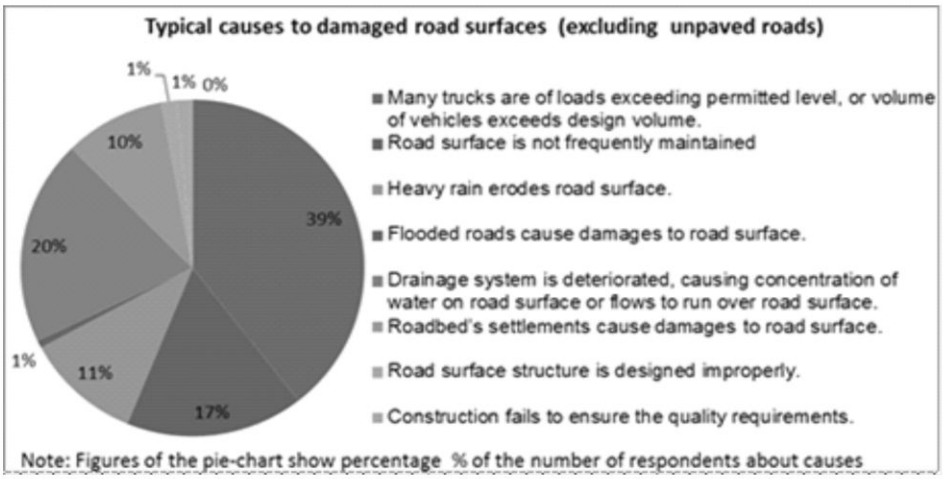


Figure 2. *Typical causes to damages of road surfaces (excluding unpaved road surfaces)*

a. Road surface is peeled off, cratered due to frequent concentration of water

b. Water concentration at lower points on road surface (marked area)

Notes: Photos taken on Dong An - Phong Du route in Van Yen district, Yen Bai province, Vietnam

Figure 3. *Adverse effects of water concentration on road surface*

4.1.2 Polished or ravelling aggregate on macadam and aggregate road surfaces

Beside the general causes such as heavy loads, poor compaction or inproper maintenance, this type of damages is elementary caused by overflows on road surface at high speed. This problem frequently occurs in road sections with high longitudinal slopes when the side ditch system doesn't work properly, causing runoffs to concentrate on road surface.

The secondary cause is the usage of improper types of materials. In fact, the aggregate material types used for construction of rural road surfaces are partly naturally exploited materials with bad quality. An example shown in Figure 4 illustrates the aggregate materials include granular particles with sizes exceeding the permitted level.

a. Runoffs acrossing road surface cause erosion

b. Surface course materials are eroded and washed away

Note: Photos taken on Dong An - Phong Du route in Van Yen district, Yen Bai province, Vietnam

Figure 4. *Surface course to be eroded, washing away materials*

4.1.3 Mudy surface and rutting of unpaved surface

Due to financial constrains, many road surfaces are compacted soil. That is the reason of forming quickly of weel path rutting in the rainy seasons. In fact, the drainage system on these roads is not focused; and the road maintenance works are not frequently carried out. The water concentration on road surfaces upon rains together with loads imposed by vehicles is a basic cause to difficult travelling during rainy seasons on unpaved road surfaces.

4.2 Slope failures

4.2.1 Cut-slopes

Cut-slope failure is a relatively popular phenomenon on rural roads in Northern mountain region. Due to difficulties of the mountainous terrain and the use of limited design technical specification, many local roads in the region own very large-and-deep cut talus, causing landslides especialy during the rainy season. An evidence to prove it is that the damages of slopes often occur after heavy rains or long-lasting rains. In fact, most of cut-slopes are not installed with intercepting ditch systems with connecting structures to collect and transfer flood water out of cut-slopes. Furthermore, very few cut-slopes are installed with reinforced surface or live vegetation to increase the slope stability.

Several solutions can be applied to reduce risks of damages to cut-slopes, including:

- Frame mapping the highly landslide prone areas, then avoid planning and designing roads through these areas as much as possible. Currently, the planning of rural road network almost doesn't look at the impacts of the highly landslide prone areas.

- Setting priorities to install intercepting ditch, side ditch, water conveying ditch system and connecting structures to ensure the cut-slopes to be in dry conditions, minimize overflows on slopes especially in case of large basins above steep slopes.

- At the highly landslide prone areas, trying to minimize the height of cut-slopes. If needed, use high gradients to reduce the height of cut-slopes.

- Monitoring, checking geotechnical conditions of cut-slopes during construction. In case of differences in geotechnical condition, change the design of cut-slopes if needed to ensure the stability of slopes. This solution is especially useful if the cut-base intersects various geological layers and geological layers lies between soil and stones. For example, only excavate a not major volume of soil to get stone road base in soil mixed stone geological areas.

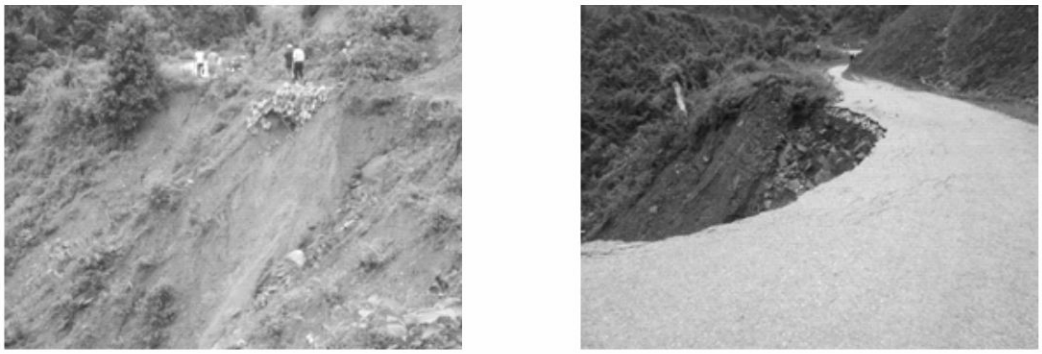
- Protecting slopes by bio-engineering measures such as grass sodding, bushes. Note to select plants with deep roots into slopes. Possibly combine bioengineering and mechanical measures such as retaining wall, slope covering frames... if necessary.

4.2.2 Fill-slopes on steep slopes (including natural slopes)

This phenomenon frequently occurs in the places of the filled road base on steep slopes with major horizontal gradient as illustrated in Figure 5. Under forces by loads of filled soil volume, the fill-slope itself may be slided or both filled base and natural steep slope are slided, causing damages. Another type of damaged filled road base on steep slopes is caused by minor friction between filled soil and natural steep slope, leading to slides of filled portions on natural steep slopes. Therefore, the usage of high filled based on steep slopes is not recommended, especially for slopes with high gradient due to high risks of slope instability. There are many causes to slides of filled bases on steep slopes.

From the perspective of road design, this type of damage doesn't occur if the horizontal alignment is selected well. In many cases, a wise selection of alignment and appropriate profile design will dramatically reduce the usage of filled base on steep slopes, thereby reducing risks of instability of filled slopes. Besides, very few design proposals of rural roads carry out detailed checking of stability of fill slopes on steep slopes.

During construction stage, the compliance of quality of road base compaction for filled portions on steep slopes with major gradient is not focused properly. Through discussion with local authorities, upon the construction of types of filled bases on steep slopes, the fill materials are extracted from cut materials of cut bases and then graded into filled bases with high elevation. Thus, the fill materials are not selected carefully and fail to meet requirements for fill materials. Moreover, this filled portion is not compacted to ensure the required compactness within the scope of whole soil base volume (generally meet the required compactness for soil layer above filled portion). The compactness of roadbeds is not ensured, which means the load bearing capacity of filled base fails to meet the design requirements.



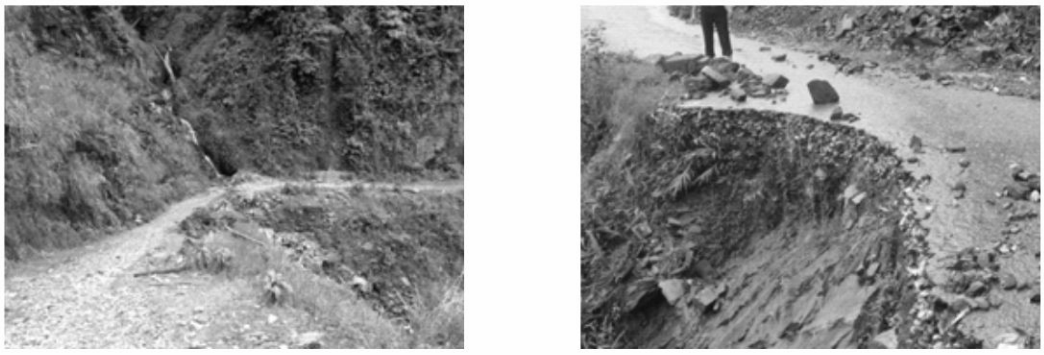
a. Slides at both cut slopes and fill slopes

b. Close look at slides of fill slopes

Note: Photos taken in Yen Thanh - Ban Dia rural road, Bac Quang district, Ha Giang province

Figure 5. *Failures of fill slopes on steep hills*

In addition to non-compliance of compaction requirements, fill slopes on steep slopes are not usually protected carefully, leading to storm water's overflowing on slope surface. At points where runoffs concentrate on fill slopes, the storm water easily penetrates into loosely compacted soil base, hence quickly reducing the load bearing capacity of slopes; as a result, the slopes are damaged. In addition, observations at many locations of slides of fill slopes on steep slopes show that in many cases, the grading and organic excavation before filling are not carried out in accordance with regulations, reducing frictions between filled base bottom and natural steep slope. The penetration of storm water into adjoining surface between filled base bottom and natural steep slope increases the risk of slides of filled portion on steep slopes (see Figure 6).



a. Runoffs across roads (due to no horizontal culverts) causes slides of fill slopes on steep slopes

b. Slides of filled portion on steep slopes with major gradient due to overflows on slopes and weak friction between filled portion and steep slopes

Note: Photos taken in rural roads from Ban Cong to Muong La district (Son La province), Tram Tau district, Ha Giang province, Vietnam (photo a) and Yen Thanh - Ban Dia rural road in Quang Binh district, Ha Giang province, Vietnam (photo b)

Figure 6. *Failures of fill slopes on steep hills due to runoffs on slopes and weak friction between filled portion bottom and steep slope*

4.3 Causes to damages and losses for drainage works

As mentioned above, the typical damages of drainage works are mainly (i) bridges, culverts, ditches to be congested; (ii) side ditches to be deposited, eroded or damaged; and (iii) bridges, culverts (including road bases) to be washed away by flashfloods.

The first two typical damages are mainly caused by inadequate maintenance. Eroded side ditches should be paid attention, particularly in steep slopes with major basins but without proper arrangement of intercepting ditch system and cross culverts to side ditches that are incapable of drainage. It is noted that leaving water to concentrate on two sides of roads due to inefficient drainage works is one of the key causes to damages of road surfaces, road bases and slopes. In the context of climate change that may result in increased extreme events such as rains, floods, the efficient operation of drainage works is an urgent need.

Regarding damages caused by flashfloods, the usage of solid structural works to eradicate damaging effects of flashfloods is infeasible for rural roads due to high costs and low efficiency (difficult to predict the timing and intensity of floods). Several preventive measures shall be focused, including (i) promptly mapping the highly flashflood prone areas to integrate into rural road planning and designing work (especially the selection of location of roads and design of drainage structures); (ii) at flashflood prone locations, the drainage works (bridges) shall have adequate spans and elevation to ensure the discharge of flow volumes; in case of non-compliance of adequate spans and elevation, it is active to use mitigation options to reduce damages once floods hit the works; (iii) regularly unblocking flood discharge routes, avoiding water concentration upstream; and (iv) focusing on planting and conserving upstream forests.

5. Orientation to solutions

Based on the causes to damages of rural roads as aforementioned, this paper recommends several measures to increase the resilience of works under the more and more severe impacts of climate factors, as below:

- Regarding planning, promptly prepare maps on warnings of risks of occurrence of extreme natural phenomena such as flashfloods, landslides... and integrate this information into planning the locations and scales of rural roads.

- Regarding survey, design works, fully comply with regulations on surveys and designs, especially surveying works and hydrological calculations, geotechnical surveys for design of slopes. The design of works, especially the selection of road surface materials and design of drainage works, shall consider the actual capabilities of maintenance of works. Special attention and priorities shall be paid to the design, arrangement of drainage works following the principle that ensures the road bases and surfaces to be in dry conditions and minimize water concentration and penetration into road surfaces, bases and slopes.

- Regarding construction, strictly comply with regulations and requirements of construction, especially the selection of materials and regulations on compaction of road bases. During construction, it is required to re-assess geotechnical conditions and other conditions, compare with design documents; if needed, make changes in design as appropriate.

- Regarding maintenance, exploitation, focus on proper allocation of resources for this work. Special attention shall be paid to maintenance of drainage system even in case of limited funding. At the same time, specific regulations on vehicles' loads corresponding to load bearing capacity of works are required.

6. Conclusions

Northern region of Vietnam take evident of a typical mountainous area with complicated topography and hydrology. The roads in this area, there fore, are vulnerable to adverse impacts of natural conditions and actual operational conditions. There are a variety of types of damages for various items of rural roads that have found in this study including road pavement failure, roadbed manfunction, and improper work of drainage system. The causes resulting from variety of abandon planning, improper design, low-quality construction, and poor maintenance have also revealed in this paoper. The findings can be used as an input for developing appropiate solutions to improve the sustainability of rural roads in the Northern mountain region of Vietnam.

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