NUMERICAL SIMULATION FOR SLOPE STABILITY ANALYSIS AND LANDSLIDE PREDICTION IN BAC KAN PROVINCE, NORTHEAST VIETNAM

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ABSTRACT

Movements down slopes of soil and rock masses are significant appearance of sliding process. The possibilities of the movements can be assessed by various methods. Among that, limit equilibrium method is very common. In this method, the slip surface is assumed to be an arc or coincidingwith the weakest surface defined in the field. In each case, a numerical model has been proposed to assess slope stability. Bac Kan is a mountainous province in the northeast Vietnam where landslides are very popular, especially in rainy season. Along the road from Cho Moi to Cho Don, 72 big landslides were recorded. The volumes of landslides can exceed 5000 m^3. The slip surfaces are either arc or along surfaces of oblique beddings. Remarkably, the biggest slides always have slip surfaces combined between arc and oblique bedding. A new numerical solution linked two available models is proposed to assess slope stability in such case. Based on results of field measurements and numerical models, influences of geological structure, physio-mechanical properties of soils and rocks, topography, thickness of weathering crust and vegetable coverage have been clearly determined. From that, a chart of landslide prediction is proposed indicating 4 zones with different possibilities of sliding which are very high, high, medium and low possibility, respectively.

1 INTRODUCTION

Landslide is a common phenomenon in the mountainous area of Vietnam, especially in rainy season (May-September). Bac Kan - a northeast mountainous province is not an exceptional. Herein, landslides have caused serious damages to the humanity and property. Bac Kan belongs to the northeast folding region with complex geological settings. The geological activities, especially neotectonic movements have created the strong sloping relief that can remarkably strengthen the occurrence of landslides. In the storm No. 2 in 2001, there were 11 large landslides with the capacity of about 16,000 m^3. These ones led to the interrupts in the national highway No. 3 and many other national highways for a long time. The cost of damage was over several billion VND. Landslides often occur in the weathering crust and highly cracked bed rocks of Phu Ngu (O_3-S_1*pn*), Bac Bun (D_1*bb*), Mia Le (D_1*ml*), Song Hien ($T_{1\text{-}2}$*sh*) and Ha Coi ($J_{1\text{-}2}$*hc*) formations. The tectonic activities has intensively weakened the strength of rock masses and made intensification of weathering process.

Numerical methods have widely applied in geotechnics, generally and in the landslide analysis and prediction particularly. In slope stability analysis, the most common method is circle slip surface. However, in the situation of Bac Kan province, the landslides with large volume (above 200 m^3) usually have complex slip surfaces. In each landslide, the upper part of soil mass has a circle slip surface and the lower one has an inclined flat surface, equivalent to the bedding surface of bed rocks. Therefore, a new procedure of calculation should be built to solve this problem.

In the paper, a software was newly programmed that permit carrying out slope stability analysis in the case of both circle and flat slip surface. Afterwards, the combination of theoretical calculation and field data can derive a suitable method for landslide prediction.

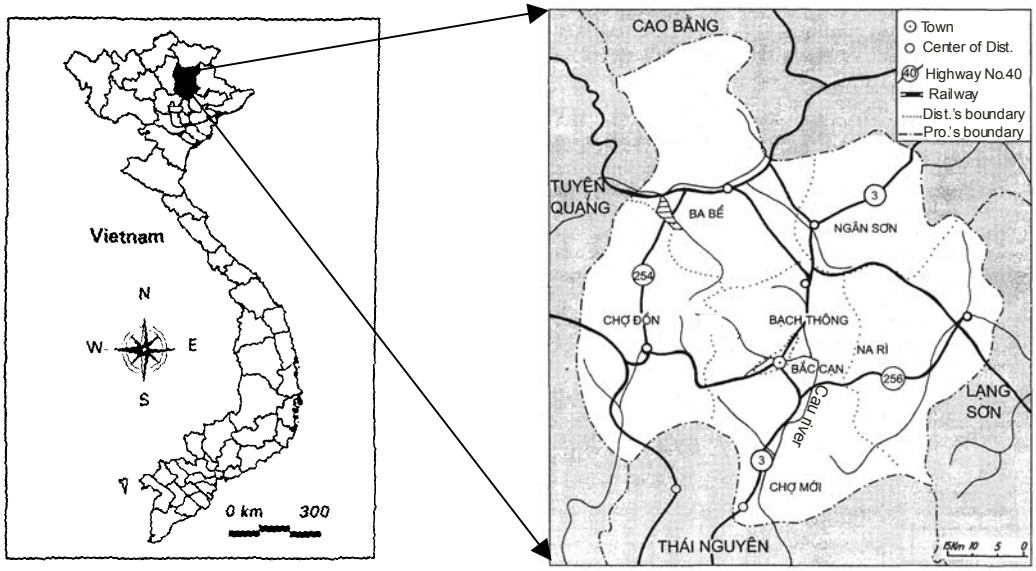

Fig. 1. Study area

2 MATERIALS AND METHODS

The database is mainly achieved from the investigation along some national highways No. 3 (from Cho Moi to Bac Kan town), No. 254 (Bac Kan town – Cho Don) and No. 256 (Bac Kan town – Na Ri). It contains geological settings of the region, levels of weathering, physical mechanical properties of soils and rocks. The most important data is a set of 72 recorded large landslides. The detail investigation was carried out for each landslide and the retrieved data contains the location, dimensions of landslide, slope angle, characteristics of soils and rocks, vegetable coverage and human activities affecting the landslide. During the investigation, 40 disturbed and 80 undisturbed samples of soils and rocks were also taken for further analysis in the laboratory. In addition, the monitoring data of daily rainfall in 2001 is an important supplement for slope stability analysis.

The research was conducted by using various methods. The order of deployment of each method is disposed in a sequence as follows (Fig. 2): the remote sensing & GIS method is applied to classify the areas of different heights, inclined angles and assume the potential areas of landslides for further research. Geological methods permit elucidating lithological composition of rocks, their ability of weakening due to weathering and define the cracked zones caused by tectonic movements. Then, the site investigation was deployed, including measurement of landslide dimensions, taking samples and field test of soil, rock mass shear strength. The samples, subsequently, were analyzed in the laboratory to define physical, mechanical properties of soils and rocks. Afterwards, the achieved data was used for slope stability analysis and landslide prediction.

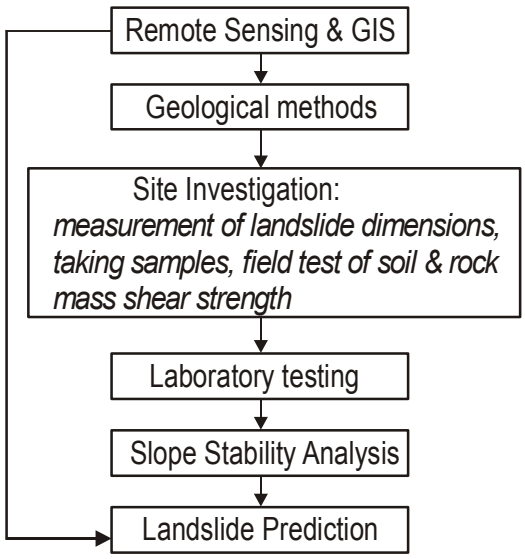

Fig. 2. The flow chart of methodology

3 SLOPE STABILITY ANALYSIS

Landslides in Bac Kan province are often occurred at the slopes of national highways. The significant remark is that the landslides only take place in rainy season. They can occur either in the weathering crust or in the highly cracked rock masses. The slip surfaces are as arc shape in the weathering crust or in the bed rocks, they coincide with bedding surfaces. The landslides with large volumes often have complex slip surfaces including both arc and flat bedding slip surfaces. The 72 recorded landslides distribute mainly in 7 regions (3 regions in Cho Don district, 2 in Bac Kan town and 2 in Cho Moi district). The volumes range from tens m^3 to over 5,000m^3, among that the volumes of 100-500 m^3 are dominant.

The slope stability can be analyzed by either limit equilibrium theory or finite element method. When the slip surface is known or pre-assumed, the limit equilibrium is commonly used. So far, the pre-assumed circle slip surface (Fig. 3) has been remarkably used by researchers and commercial softwares. In this case, the factor of safety (Fs) is calculated by using assumptions and equilibrium equations of forces and moments. The assumptions are always related to side forces of slices. In the paper, the side forces are ignored that is the way known as the ordinary (Fellinius) method and only the plane problem is dealt with. The minimum Fs is estimated by iterations. The slope is considered instability when minimum Fs smaller than 1.2. Fs is calculated as follows:

$$Fs = \frac{\sum_{i=1}^{n} (c_i l_i + W_i \cos\alpha_i tg\varphi_i)}{\sum_{i=1}^{n} W_i \sin\alpha_i}$$

i: the slice number i, W_i weght of slice, c_i, φ_i: cohesion and angle of internal friction of soil at slice bottom, l_i length of slice bottom, α_i angle of tagent at centre of slice bottom and horizontal line.

In the case of complex slip surface (Fig. 4), the upper part is calculated as same as in the circle slip surface method and the lower part is calculated as the problem of known slip surface, that means the calculation contains only the resolution of force and moment equilibrium equations, the iteration is not taken into account.

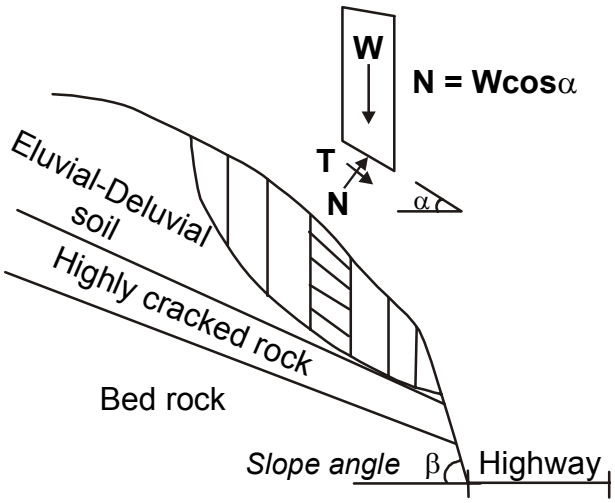

Fig. 3. Circle slip surface and forces at a slice

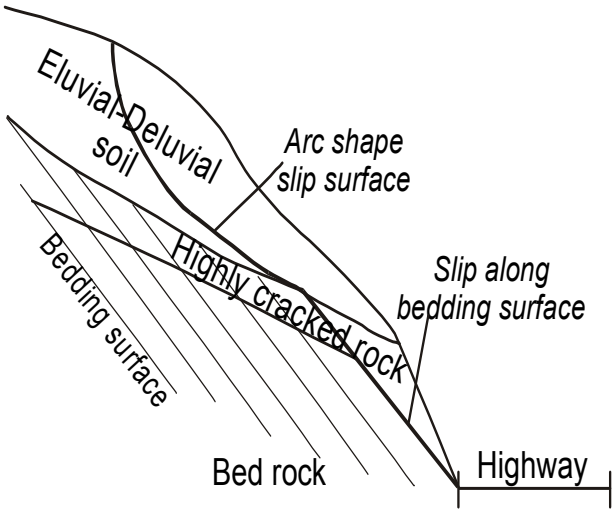

Fig. 4. Complex slip surface

The procedure of calculation was programmed as a software that permits solving both cases of circle and complex slip surface. The slope stability analysis is conducted based on dimensions of each landslide and characteristics of soils and rocks (Tab. 1). The results show that: in natural (dry) condition, most of slopes are stable, except the slopes with height of over 15m. In a slide when the soil and rock masses gets wet in a shower, the shear strength reduces sharply and the minimum Fs is smaller than 1.2. Therefore, rainfall is one of the main reason causing landslides. The calculation also indicates that landslides often take place when the slope angle above 45^0 and slope height greater than 4m.

Tab. 1. Characteristics of soil and rock

Type	Water content (%)	Wet density (g/cm^3)	Void ratio	Shear strength			
				In-situ		Saturated condition	
				φ (deg.)	c (kG/cm^2)	φ (deg.)	c (kG/cm^2)
Eluvi-Deluvi	24	1.81	0.86	29.9	0.21	24.0	0.11
Rock mass	14	2.01	-	33.9	0.20	27.6	0.11

(φ, c : angle of internal friction and cohesion of soil)

4 LANDSLIDE PREDICTION

The above results show that the stability of slopes in Bac Kan province depends on relief, geological settings, thickness of weathering crust, shear strength of soil & rock masses, vegetable coverage and rainfall. However, the estimation of rainfall, especially shower is a task required meteorological approaches that can deal with another research and is not detaily studied in this paper.

The site investigation of 72 landslides indicated that they only occurred where bed rocks strongly influenced by faults or the direction of oblique beddings coincides with inclined direction of slopes; the slopes are constituted by elluvial-delluvial soils or highly cracked rocks; the thickness of weathering crust of over 5m usually met at landslides over $500m^3$. The high density of vegetable coverage is taken place at almost landslides. Therefore, the role of vegetable coverage in slope instability is ignorable. The combination of these factors and relief (slope height, angle) leads to the flow chart of landslide prediction (Fig. 5).

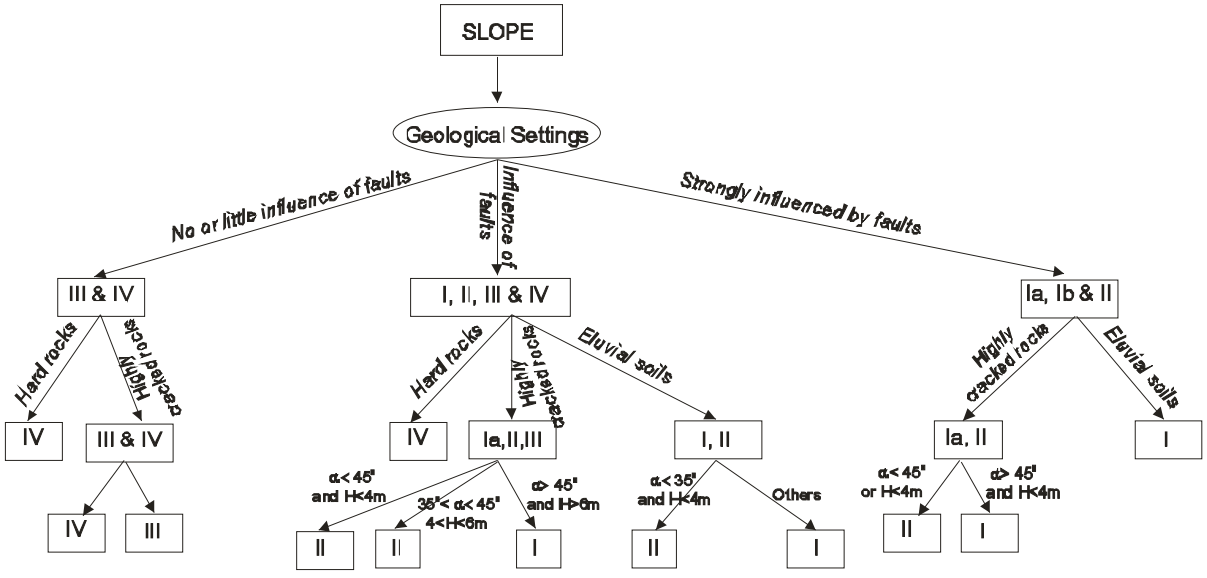

Fig. 5. The flow chart of landslide prediction

α, H – slope angle and height, I – Very high possibility of landslide
II – High possibility III, IV – Medium and Low possibility

The zone of very high possibility of landslide (I) distributes mainly along the Cau river, especially the segment of highway No. 254 from Bac Kan town to Cho Don. All area of the zone is covered by eluvial-deluvial soils.

The zone of high possibility (II) is widely distributed. It is next to the zone I. However, the height and slope angles are smaller. Almost area of this zone is covered by eluvial-deluvial soils but some small parts are at the region of highly cracked bed rocks of Bac Bun and Mia Le formations.

The zone III - medium possibility is met at low steep relief. The zone of low possibility (IV) distributes in some small areas where the hard rocks deposed and where the human activities do not change strongly the natural slope angles.

5 CONCLUSION

The methodology including remote sensing & GIS, geology, field and laboratory tests has provided sufficient data for analysis and prediction of landslides in Bac Kan province. The model solving both problems of circle and flat bedding slip surfaces permits elucidating the instability of slopes from that two main reasons of landslides are defined. The first one is excess slope heights and angles; the second is the reduction of soil & rock mass shear strength due to getting wet, especially in showers of rainy season. The analysis of the factors such as geology, shear strength of soils, rocks, topography and vegetable coverage leads to a flow chart of landslide prediction with four levels, from low to very high possibility of slope instability.

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