Science on Natural Resources and Environment
Journal homepage: tapchikhtnmt.hunre.edu.vn

BLOCK THEORY ANALYSES FOR ROCK SLOPE STABILITY. A CASE STUDY ALONG 3B HIGH WAY, XUAT HOA AREA, BAC KAN PROVINCE

Nguyen Quang Minh[1], Phi Truong Thanh[2], Do Manh Tuan[2], Tran Xuan Truong[2], Le Trung Kien[2], Nguyen Thi Phuong Thanh[2], Vu Thi Hong Cam[2]
[1]Hanoi University of Mining and Geology, Vietnam
[2]Hanoi University of Natural Resources and Environment, Vietnam

Received 17 October 2020; Accepted 16 December 2020

Abstract

By developing the application of Block Theory (Goodman and Shi, 1985) to analyze fracture orientations at 32 survey sites along the 3B highway, about 12 km long, Xuat Hoa area, Bac Kan province, the analytical results showed that 06 rock slope surfaces at the survey sites: BK-15, BK-17, BK-34, BK-50, BK-52, BK-63 can be formed blocks that have a risk of high failure. The statistical results have also shown that, the rock slope surface with the group of fracture orientations: 315º/70º has 3/10 rock slope surfaces that have a risk of high failure; 002º/70º has 2/4 rock slope surfaces that have a risk of high failure; 032º/70º has 1/11 rock slope surface that has a risk of high failure; 212º/70º has no rock slope surface that has a risk of slope failure. These results showed that the fracture orientation of rock slope surfaces in the NW - SE direction can be formed blocks to be lower than the rock slope surfaces in the NE - SW direction and sub-horizontal direction.

Keywords: Block theory; Key block; Fracture orientation; Slope stability; 3B Highway.

Corresponding author. Email: ptthanhdc@hunre.edu.vn

1. Introduction

Vietnam is a country that has a two-thirds area of the mountainous region. Many roads are opened in this area. In the rain and storm season, the slope surface of these roads often causes failure, serious damage to the economy and people's lives in the area (Fig. 1). Currently, the slope failure along the road is one of the most important problems that the localities in the mountainous provinces of Vietnam are facing. The slope failure research in Vietnam has been conducted since the early 2000s. However, they are almost projects; there are very few papers published at this time. After that, most studies were conducted on the basis of the processing satellite image, terrain, geomorphology, etc. to build the zoning map and forecast the risk of a landslide (Truong et al., 2011; Nguyen et al., 2012; Tran et al., 2013; Bui et al., 2016) [9, 5, 8, 1].

In the year 1985, the Block Theory method of Goodman and Shi was developed and continuously extended to deal with the identification and analysis of the stability of the critical blocks. The main idea of block theory is the prevention of the movement of keyblocks. Therefore, the keyblock analysis has been receiving a lot of attention among engineers because in an actual engineering project, it loses its stability first after excavation. Um and Kulatilake (2001) [11] used major discontinuities to perform rock slope kinematic and block theory analyses along the total length (1750 m) of the shiplock slopes of the Three Gorges Dam Site in China. The analytical result has been divided into 50 m segments. Base on stereonet projection, the keyblocks (Type I) and/or potential keyblocks (Type II) were found in only five segments of the Shiplock slopes. Besides, the study was also indicated that the dip angle of the cut slope should be less than about 60º to avoid the creation of a keyblock on the proposed Shiplock slopes. Similarly, Wangsa (2008) also used major discontinuities to perform a kinematic and block theory analysis of the rock slope stability of the entry road to Fraser's Hill in Pahang, Malaysia. The stereo-plot and then analyzed using kinematic to determine the maximum safe slope angle for the rock slope and block theory to determine the key blocks types (Type I) and potential key blocks types (Type II) of the rock slope. Next year, Quoc Phi Nguyen (2009) [7] has used the Block Theory method of Goodman and Shi

(1985) [2] to identify the potential keyblocks along the Bong Hwang tunnel, South Korea. Then, the obtained result was examined using the ROCK3D software. Kulatilake et al. (2011) conducted the kinematic and block theory analyses for rock slopes to evaluate the slope stability, and the numerical results have shown that the maximum safe slope angles obtained from the kinematic analysis are less than or equal to those obtained from block theory analysis, that verified that the results based on keyblock theory were reality. Quoc Phi Nguyen and Truong Thanh Phi (2014) [6] have applied the Block Theory method to find potential failure along the road 6, belonging to Dong Bang, Mai Chau district of Hoa Binh province, Vietnam. The analytical results have determined the position of plane failure, wedge failure and toppling failure along this road.

In this paper, we continue to develop the approach of Goodman and Shi (1985) [2] to identify key blocks along the 3B highway, Xuat Hoa area, Bac Kan province. The results of this study are an important database for the design and construction of the 3B highway in the future.

Figure 1: Rock failure block at the km 116 + 100 on the 3B highway

2. Method of potential keyblock analysis

This paper also presents the analytical results of fracture sets which can form potential keyblock. The identification of potential keyblock is carried out according to the Block Theory method of Goodman and Shi (1985) (Fig. 2).

According to Block Theory method, the space above the excavation surface is a free plane, designated as a space pyramid (SP); the joint plane subset of half space determining a block pyramid designated as a joint pyramid (JP); the set of shifted excavation half spaces designated as the excavation pyramid (EP). The block pyramid (BP) is then the intersection of the joint pyramid and the excavation pyramid for a particular block:

$$BP = JP \cap EP \qquad (2)$$

For a block to be fine, the block pyramid must be empty.

A block is finite if and only if:

$$JP \cap EP = \Phi \qquad (3)$$

The equation (2) is equivalent to stating that a block is finite if and only if its joint pyramid is entirely contained in the space pyramid, that is, if and only if:

$$JP \subset SP \qquad (4)$$

In Figure 2, a lower-focal-point stereographic projection of four joint sets and a free plane (slope face 5). Assuming that the rock mass is below slope face 5, SP is the area inside the great circle for slope face 5

The only removable blocks (keyblock) are therefore those corresponding to joint pyramids 0011, 1001 and 0001. Where the number 0 corresponds to the symbol U and defines the half-space above a plane; the number 1 corresponds to the symbol L and identifies the half-space below a plane.

The potential keyblock analysis of each fracture domain in this study is carried out by using the Block Theory method of Goodman and Shi (1985). The obtained result is shown in Fig. 2.

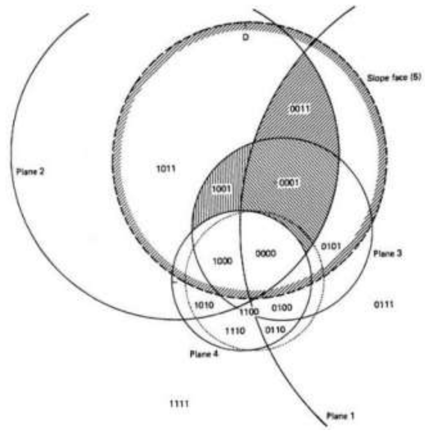

Figure 2: Stereonet projection of data of 1) joint set ($080^{o}/75^{o}$); 2) joint set ($330^{o}/65^{o}$); 3) joint set ($030^{o}/40^{o}$); 4) joint set ($270^{o}/10^{o}$), 5) free surface ($000^{o}/60^{o}$) with the free surface of slope face 5 only (Goodman and Shi, 1985) [2]

Material

Data sources used in this study are the fracture orientations that were selected from 32 survey sites on the rock slope surface along the 3B highway, Xuat Hoa area, Bac Kan province, Vietnam. The collected data were measured randomly using a compass at each survey site (Fig. 3 and Tab. 1).

Table 1. Location of the survey sites, number of fractures and geological ages

No	Survey sites	Longitude	Latitude	Fracture number	Geological ages
1	BK-15	105°53’52.2”	22°05’37.6”	127	$D_{2-3}th$
2	BK-17	105°53’53.7”	22°05’09.2”	103	$D_{2-3}th$
3	BK-21	105°53’54.4”	22°05’49.8”	023	$D_{2-3}th$
4	BK-26	105°53’56.2”	22°05’55.8”	116	$D_{2-3}th$
5	BK-27	105°53’59.8”	22°05’59.1”	122	$D_{2-3}th$
6	BK-28	105°54’03.9”	22°05’59.4”	096	$D_{2-3}th$
7	BK-30	105°54’07.0”	22°05’58.2”	137	$D_{2-3}th$
8	BK-34	105°54’19.5”	22°06’02.5”	096	$D_{2-3}th$
9	BK-35	105°54’23.1”	22°06’03.9”	105	$D_{2-3}th$
10	BK-41	105°54’46.9”	22°06’15.1”	188	$D_{2-3}th$
11	BK-50	105°52’21,8”	22°06’15.6”	136	$D_{2-3}th$
12	BK-52	105°55’28.2”	22°06’09.3”	113	$D_{1-2}nq_2$
13	BK-53	105°55’30.8”	22°06’04.6”	135	$D_{1-2}nq_2$
14	BK-57	105°55’44.7”	22°05’53.4”	071	D_1ml_2
15	BK-58	105°55’48.1”	22°05’53.1”	090	D_1ml_2
16	BK-59	105°55’49.6”	22°05’50.1”	079	D_1ml_2
17	BK-61	105°55’49.8”	22°05’44.6”	165	D_1ml_2
18	BK-62	105°55’50.3”	22°05’41.8”	076	D_1ml_2

19	BK-63	105°55’54.6”	22°05’41.4”	065	D_1ml_2
20	BK-66	105°56’00.5”	22°05’42.3”	104	D_1ml_2
21	BK-68	105°56’03.5”	22°05’38.2”	120	D_1ml_2
22	BK-69	105°56’06.2”	22°05’34.7”	103	D_1ml_2
23	BK-72	105°56’07.7”	22°05’31.5”	070	D_1ml_2
24	BK-74	105°56’14.8”	22°05’32.1”	119	D_1ml_2
25	BK-75	105°56’26.0”	22°05’28.8”	099	$D_{1-2}nq_1$
26	BK-76	105°56’31.8”	22°05’27.7”	128	$D_{1-2}nq_1$
27	BK-78	105°56’38.1”	22°05’27.2”	152	$D_{1-2}nq_1$
28	BK-79	105°56’41.8”	22°05’27.3”	155	$D_{1-2}nq_1$
29	BK-80	105°56’44.1”	22°05’24.7”	158	$D_{1-2}nq_1$
30	BK-81	105°56’45.6”	22°05’20.6”	172	D_1ml_2
31	BK-82	105°56’49.2”	22°05’18.6”	215	D_1ml_2
32	BK-83	105°56’52.1”	22°05’15.9”	102	D_1ml_2

Locations of survey sites in Tab. 1 are plotted in Fig. 3.

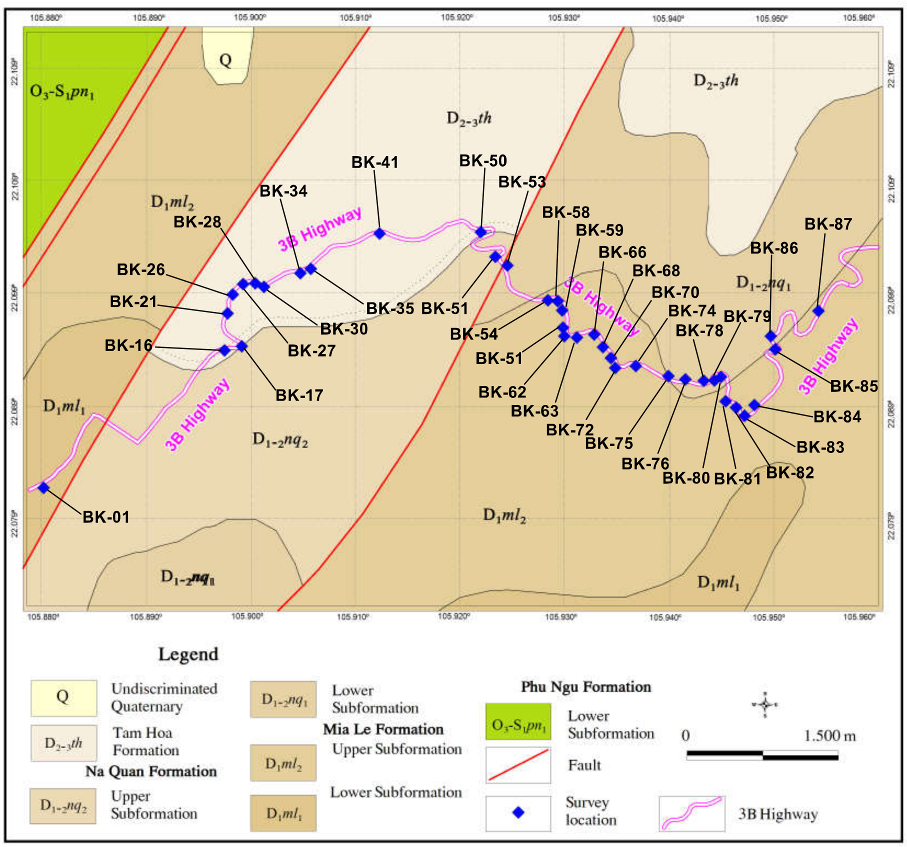

Figure 3: Geological map, minimized from scale 1: 200.000 and survey locations (Nguyen et al, 2000)

Where: $D_{2-3}th$: Tam Hoa formation: polymictic conglomerate, gritstone, lay shale and limestone bearing; D_1ml_2: Mia Le Formation: clayish siltstone, marlaceous shale; $D_{1-2}nq_1$: Na Quan formation: marlaceous shale; $D_{1-2}nq_2$: Na Quan formation: Shale interbedded with limestone.

3. Results

The keyblock analysis along the 3B highway, Xuat Hoa area, Backan province is carried out by using Block theory of Goodman and Shi (1985) [2] (Fig. 4).

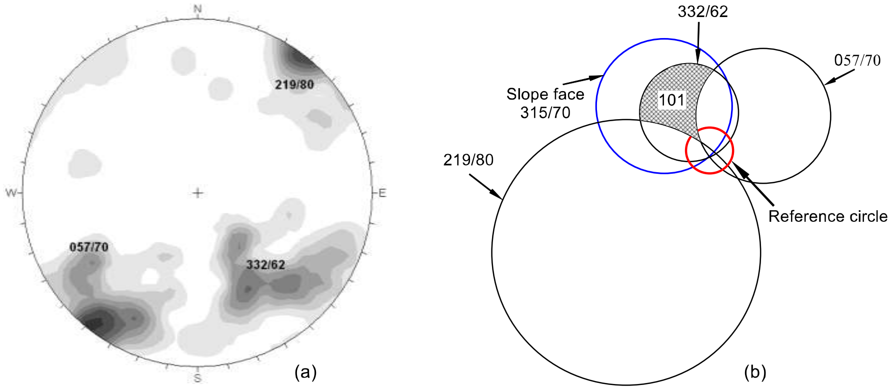

Figure 4: a) Stereonet of fracture orientations; b) Potential keyblock analysis (101, slide on set 2) of fracture sets: 332°/62°, 057°/70° and 219°/80° together with slope surface orientation 315°/70° at survey site BK-15

Similarly, the potential keyblock analysis of the other remaining fracture domain along the 3B highway, Xuat Hoa area, Bac Kan province, Vietnam are also carried out and recorded in Tab. 2.

Table 2. The potential keyblocks formed at each survey site along the proposed 3B highway, Xuat Hoa area, Bac Kan province, Vietnam

No	**Survey sites**	**Fracture set**	**Slope orientation**	**Key block**	**No**	**Survey sites**	**Fracture set**	**Slope orientation**	**Key block**
1	BK-15	057°/70°; 332°/62°; 219°/80°.	315°/70°	057°/70°; 332°/62°; 219°/80°. 101, slide on set 2	17	BK-61	048°/77°; 238°/73°; 157°/70°; 287°/59°	032°/70°	0
2	BK-17	232°/78°; 327°/62°; 022°/55°.	315°/70°	232°/78°; 327°/62°; 022°/55°. 101, slide on set 2	18	BK-62	017°/68°; 041°/83°; 216°/66°; 181°/49°	032°/70°	0
3	BK-21	240°/81°; 321°/56°	315°/70°	0	19	BK-63	009°/75°; 058°/60°; 277°/66°; 233°/77°.	032°/70°	009°/75° 058°/60° 277°/66° 233°/77°. 0011, slide on set 2
4	BK-26	049°/76°; 183°/74°; 265°/76°	315°/70°	0	20	BK-66	071°/75°; 337°/70°; 026°/51°.	032°/70°	0
5	BK-27	233°/68°; 008°/62°; 063°/64°; 109°/73°.	315°/70°	0	21	BK-68	063°/74°; 340°/61°; 286°/68°; 258°/76°.	032°/70°	0

6	BK-28	014/78; 197/76; 062/80; 252/70; 135/77	315°/70°	0	22	BK-69	077°/80°	032°/70°	0
7	BK-30	022/58; 336/69; 147/35.	315°/70°	0	23	BK-72	068°/62°; 342°/72°; 026°/50°.	032°/70°	0
8	BK-34	090°/41°; 348°/32°; 265°/51°.	315°/70°	090°/41°; 348°/32°; 265°/51°; 101, slide on set 2	24	BK-74	057°/74°; 280°/56°; 247°/73°; 345°/62°.	032°/70°	0
9	BK-35	342°/77°; 256°/78°; 090°/81°; 314°/68°.	315°/70°	0	25	BK-75	266°/73°; 026°/72°; 218°/79°; 167°/78°.	032°/70°	0
10	BK-41	343°/64°; 058°/62°; 233°/62°	002°/70°	0	26	BK-76	257°/79°; 085°/80°; 028°/72°; 177°/79°.	212°/70°	0
11	BK-50	344°/61°; 084°/43°; 246°/69°.	002°/70°	344°/61°; 084°/43°; 246°/69°. 011, slide on set 1	27	BK-78	358°/59°; 257°/77°; 102°/75°; 077°/64°; 039°/65°.	212°/70°	0
12	BK-52	094°/62°; 001°/64°; 251°/62° 176°/51°.	002°/70°	094°/62°; 001°/64°; 251°/62°; 176°/51°. 1011, slide on set 2	28	BK-79	256°/80°; 083°/71°; 020°/71°; 179°/78°.	212°/70°	0
13	BK-53	100°/75°; 041°/52°; 254°/68°; 003°/70°.	002°/70°	0	29	BK-80	291°/69°; 071°/74°; 191°/77°.	212°/70°	0
14	BK-57	034°/78°; 291°/57°.	032°/70°	0	30	BK-81	281°/79°; 077°/80°; 167°/74°.	212°/70°	0
15	BK-58	037°/82°; 220°/84°; 249°/64°; 300°/78°; 314°/34°.	032°/70°	0	31	BK-82	264°/68°; 170°/73°; 034°/75°.	212°/70°	0
16	BK-59	059°/74°; 091°/77°; 254°/71°; 287°/68°.	032°/70°	0	32	BK-83	251°/68°; 083°/78°; 004°/78°; 180°/80°.	212°/70°	0

The statistical results in Tab. 2 show that the combination of fracture sets and rock slope orientation at each survey site can form potential keyblocks:

1) At survey site BK-15, the fracture sets (057º/70º, 332º/62º, 219º/80º) and slope orientation of 315º/70º can form keyblock 101, slide on set 2;

2) At survey site BK-17, the fracture sets (232º/78º, 327º/62º, 022º/55º) and slope orientation of 315º/70º can form keyblock 101, slide on set 2;

3) At survey site BK-34, the fracture sets (090º/41º, 348º/32º, 265º/51º) and slope orientation of 315º/70º can form keyblock 101, slide on set 2;

4) At survey site BK-50, the fracture sets (344º/61º, 084º/43º, 246º/69º) and slope orientation of 002º/70º can form keyblock 011, slide on set 1;

5) At survey site BK-52, the fracture sets (094º/62º, 001º/64º, 251º/62º, 176º/51º) and slope orientation of 002º/70º can form keyblock 1011, slide on set 2;

6) At survey site BK-63, the fracture sets (009º/75º, 058º/60º, 277º/66º, 233º/77º) and slope orientation of 032º/70º can form keyblock 0011, slide on set 2.

The comparative results between the kinematic analysis by using Hoek and Bray (2004)'s application (Thanh et al, 2018) [10] and potential keyblock by using Block Theory method of Goodman and Shi (1985) [2] have shown that 06 survey sites have an overlap of a high risk of slope failure at survey sites: BK-15, BK-17, BK-34, BK-50, BK-52, BK-63. These results are the basis for the design and construction of the proposed 3B highway.

4. Conclusions

The analytical results of fracture orientations at 32 survey sites along the 3B highway, about 12 km long, Xuat Hoa area, Bac Kan province using Goodman and Shi (1985) [2] showed that 06 rock slope surfaces at the survey sites: BK-15, BK-17, BK-34, BK-50, BK-52, BK-63 can be formed blocks that have a risk of high failure. The statistical results also showed that, the rock slope surface with the group of fracture orientations: 315º/70º has 3/10 rock slope surfaces which have a risk of high failure; 002º/70º has 2/4 rock slope surfaces which have a risk of high failure; 032º/70º has 1/11 rock slope surface which has a risk of high failure; 212º/70º has no rock slope surface which has a risk of slope failure. This result shows that the fracture orientation of the rock slope surface in the NW - SE direction can be formed blocks to be lower than the rock slope surface in the NE - SW direction and sub-horizontal direction. These results have important significance for planning and designing rock slope stability on the 3B high way.

Acknowledgments: *This research is supported by the Project of "Research on the application of Block Theory to assess the risk of slope failure along the highway. Case study from km 0 to km 80 on the 3B highway", Code: TNMT.2018.03.18 of the Ministry of Natural Resources and Environment, within the time 2018 - 2020.*

REFERENCES

[1]. Bui, T. V., Nguyen, S. H. and Nguyen, H. T., (2016). *Assessment of slope stability in a landslide area in B'LaoWard, Bao Loc city, Lam Dong province and solutions to prevent landslides*. Science and Technology development, 19: 76 - 85.

[2]. Goodman, R.E and Shi, G., (1985). *Block theory nad its application to rock engineering*. Prentice Hall, Englewood Cliffs, NJ.

[3]. Nguyen KQ, Dinh TT, Tran VT, Dao DT, Le VC, Nguyen DD, Nguyen TV, Nguyen VH, Pham VH, Phan CT, Tong DT, Tran TT, Trinh D, Vu K (2000). *Geological and Mineral Resources Map of Viet Nam on 1:200.000: Backan (F-48-XVI).* (Department of Geology and Minerals of Viet Nam, Ha Noi.

[4]. Nguyen, Q. P., (2009). *Analysing rock stability using block theory and 3D surveying tools*. PhD thesis, Paichai University, Korea: 149.

[5]. Nguyen, T., Nguyen, D. D. and Uong, D. K., (2012). *Integration of analytical hierarchy process model (AHP) into GIS to establish a landslide hazard map of Quangtri province*. Hue University Journal of Science, 74B (5): 143 - 155.

[6]. Phi, N.Q. and Thanh, P.T., (2014). *Rock slope stability analysis using block theory and probabilistic approach: An application at national road No 6, Vietnam.* In GeoInformatics for

Spatial-Infrastructure Development in Earth & Allied Sciences GIS-IDEA. ISBN: 978-604-80-0917-5, 209 - 217.

[7]. Phi, N.Q., (2009). *Analysing rock stability using block theory and 3D surveying tools*. PhD thesis, Paichai University, Korea: 149.

[8]. Tran, M. L., Nguyen, Q. H., Nguyen, T. K., Hoang, D. T. and Bui, B. T., (2013). *Forecast the risk and intensity of landslide in the Backan city area*. Vietnam institute for building science and technology (IBST), No 3 and 4.

[9]. Truong, P. M., Nguyen, T. D., Tran, T. A. and Nguyen, V. N., (2011). *A study on landslides in Danang city by using remote sensing and GIS technology*. Proceeding GIS 2011 conference, pp. 230 - 237.

[10]. Truong Thanh Phi, Hong Thinh Phi, Viet Ha Nguyen (2018). *Rock slope failure blocks and their relation to tectonic activity: A case study in 3B highway, Xuat Hoa area, Bac Kan province, Vietnam*. Bulletin of the Iraq Natural History Museum, Vol 15, No 2, pp. 207 - 223.

[11]. Um, J.G., Kulatilake, P.H.S.W., (2001). *Kinematic and Block Theory Analyses for Shiplock Slopes of the Three Gorges Dam Site in China*. Geotechnical and Geological Engineering 19, pp. 21 - 42.