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ROCK SLOPE FAILURE BLOCKS AND THEIR RELATION TO TECTONIC ACTIVITY: A CASE STUDY IN 3B HIGHWAY, XUATHOA AREA, BACKAN PROVINCE, VIETNAM

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ABSTRACT

This paper presents the results of the slope failure analyses from fracture distributions and their relation to tectonic activity; the analytical results have indicated that the phenomena of plane failure, wedge failure and toppling failure can occur at almost of the survey sites within the study area.

The statistical data show that the fracture orientation mainly develop in the E-W, N-S and NW-SE due to the influence of tectonic activity. The occurrence of them together with the rock slope surface orientation has formed plane failure on the slope surface of the 3B highway in the E-W direction and the types of wedge failure and toppling failure on the slope surface of the highway in the N-S and NW-SE direction.

Keywords: Fracture, Plane failure, Toppling failure, Wedge failure, 3B highway.

INTRODUCTION

The slope failure occurs quite commonly along roads in the mountainous provinces of Vietnam; their occurrence is not only affects economic activities but also threatens the lives of people, impact negatively on the environment. The cause of the slope failure is mainly due to the imbalance of rock mass on the slope surface along with the occurrence of storms and underground water (Do and Nguyen, 2013). At present, 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 researches in Vietnam have been conducted since the early 2000s. However, they are almost project; there are very few papers published at this time. After that, most studies were conducted on the basis of processing satellite image, terrain, geomorphology, etc. to build the zoning map and forecast risk of landslide (Truong *et al.*, 2011; Nguyen *et al.*, 2012; Tran *et al.*, 2013; Bui *et al.*, 2016; Nguyen, 2016).

From the other hand, the above studies do not take into account the relationship between landslide and fracture, caused by tectonic activity in the Earth's crust, while the other studies on the relationship between fractures and failure have also considered by Wittke (1965), Muller (1968), Markland (1972), Hocking (1976), Haines and Terbrugge (1991). Some studies specifically addressed the landslide related to the tectonic movement (Youd, 1978; Harp and Noble, 1993; Harp *et al.*, 2003). Recently, the other authors of Vietnam have developed the Block Theory of Goodman and Shi (1985) to analyze slope failure based on fracture orientation and slope surface direction (Nguyen and Phi, 2014).

The aim of this paper is to analyse the results of the relationship between the formation of failure blocks on the slope surface and tectonic activity along the 3B highway in Xuathoa area, Backan province, Vietnam by using Hoek and Bray's application (2004).

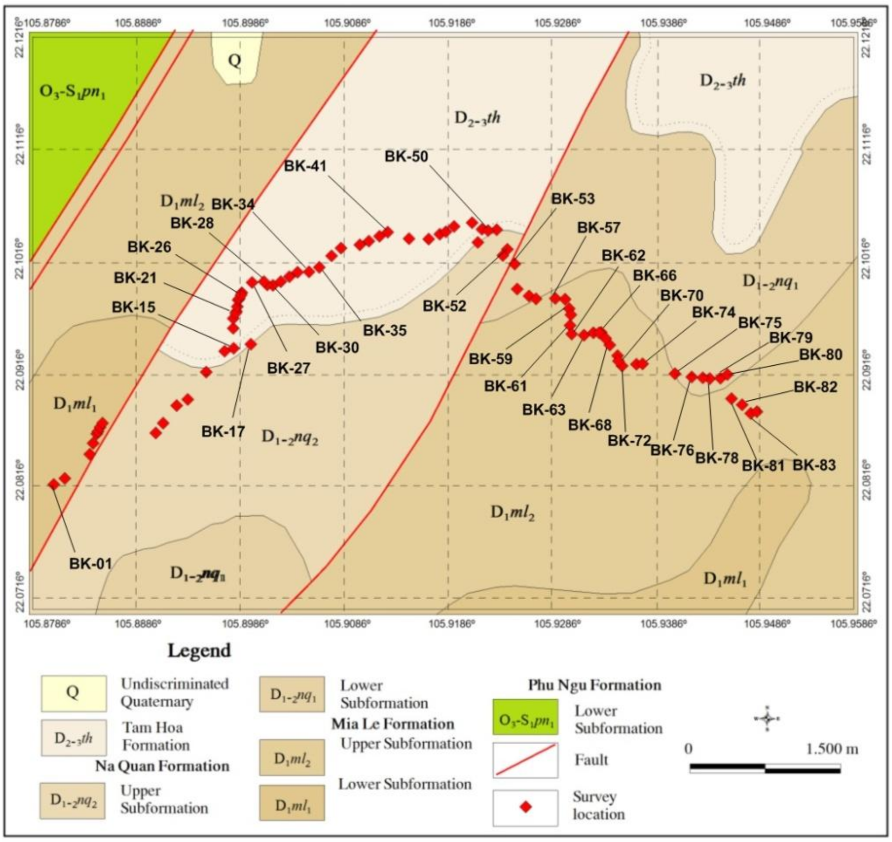
MATERIALS AND METHODS

Materials

Data sources used are the fracture orientations, which selected from 33 survey sites on the slope surface along the 3B highway in Xuathoa area, Backan province, Vietnam. The collection data were measured randomly using compass at each survey site (Map1, Tab.1).

Table (1): Location of the survey sites, number of fractures and rock slope surface orientation.

No.	Survey sites	Longitude (Degree)	Latitude (Degree)	Slope surface orientation	Fracture number	Geological age
1.	BK-01	105.879951^0	22.081889^0	140/70	73	$D_1 ml_1$
2.	BK-15	105.898139^0	22.093861^0	345/65	127	$D_{2-3} th$
3.	BK-17	105.899778^0	22.094222^0	250/75	103	$D_{1-2} nq_2$
4.	BK-21	105.898444^0	22.097167^0	280/75	23	$D_{2-3} th$
5.	BK-26	105.898944^0	22.098833^0	320/75	116	$D_{2-3} th$
6.	BK-27	105.899944^0	22.099750^0	350/70	122	$D_{2-3} th$
7.	BK-28	105.901100^0	22.099820^0	356/75	96	$D_{2-3} th$
8.	BK-30	105.901944^0	22.099500^0	370/75	137	$D_{2-3} th$
9.	BK-34	105.905417^0	22.100694^0	370/75	96	$D_{2-3} th$
10.	BK-35	105.906417^0	22.101083^0	325/75	105	$D_{2-3} th$
11.	BK-41	105.913028^0	22.104194^0	350/75	188	$D_{2-3} th$
12.	BK-50	105.922694^0	22.104278^0	340/75	136	$D_{2-3} th$
13.	BK-52	105.924500^0	22.102583^0	90/75	113	$D_{1-2} nq_2$
14.	BK-53	105.925222^0	22.101278^0	45/60	135	$D_{1-2} nq_1$
15.	BK-57	105.929083^0	22.098167^0	15/75	71	$D_1 ml_2$
16.	BK-58	105.930028^0	22.098083^0	60/80	90	$D_1 ml_2$
17.	BK-59	105.930444^0	22.097250^0	80/80	79	$D_1 ml_2$
18.	BK-61	105.930500^0	22.095722^0	115/70	165	$D_1 ml_2$
19.	BK-62	105.930639^0	22.094944^0	10/75	76	$D_1 ml_2$
20.	BK-63	105.931833^0	22.094833^0	350/75	65	$D_1 ml_2$
21.	BK-66	105.933472^0	22.095083^0	30/75	104	$D_1 ml_2$
22.	BK-68	105.934306^0	22.093944^0	65/70	120	$D_1 ml_2$
23.	BK-69	105.935058^0	22.092972^0	60/70	103	$D_1 ml_2$
24.	BK-72	105.935472^0	22.092083^0	50/70	70	$D_1 ml_2$
25.	BK-74	105.937444^0	22.092250^0	25/70	119	$D_1 ml_2$
26.	BK-75	105.940556^0	22.091333^0	210/70	99	$D_{1-2} nq_1$
27.	BK-76	105.942167^0	22.091028^0	210/70	128	$D_{1-2} nq_1$
28.	BK-78	105.943917^0	22.090889^0	180/70	152	$D_{1-2} nq_1$
29.	BK-79	105.944944^0	22.090917^0	210/70	155	$D_{1-2} nq_1$
30.	BK-80	105.945583^0	22.091242^0	260/75	158	$D_{1-2} nq_1$
31.	BK-81	105.946000^0	22.089056^0	230/70	172	$D_1 ml_2$
32.	BK-82	105.947000^0	22.088500^0	145/75	215	$D_1 ml_2$
33.	BK-83	105.947806^0	22.087750^0	190/75	102	$D_1 ml_2$



Map (1): Geological map, minimized from scale 1: 200.000 and survey locations. (Followed by Nguyen *et al.* (2000))

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

Method of slope failure analysis

The analyses of plane failure, wedge failure, toppling failure and circular failure were carried out by Hoek and Bray's application (2004), based on the fracture orientation; the analytical results will indicate the types of plane failure, wedge failure, toppling failure and circular failure on the rock slope surface as shown in the figures below.

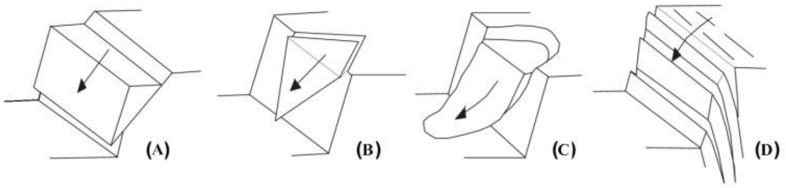


Plate (1): (A) plane failure, (B) wedge failure, (C) circular failure, (D) toppling failure (Followed by Hoek and Bray (2004)).

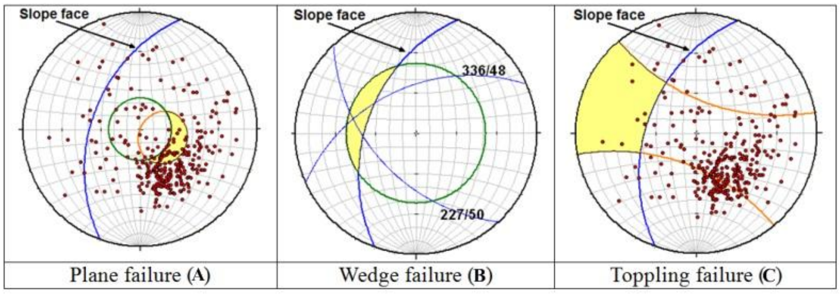


Diagram (2): (A) Plane failure, (B) wedge failure and (C) toppling failure (Followed by Hoek and Bray (2004)).

RESULTS AND DISCUSSION

Results

The slope failure analysis and their relation to tectonic activity were conducted according to Hoek and Bray's application (2004) at 33 survey sites with 3813 fracture orientations along the 3B highway in Xuathoa area, Backan province, Vietnam (Map. 1). The slope failure analysis at each survey site was conducted with the input parameters as the fracture orientation measurement, slope surface orientation and friction angle. In this case, the friction angle for the marlaceous shale is determined to be 25^0; the analytical results indicated that almost survey sites can occur plane failure, wedge failure and toppling failure, such as the survey site BK-82 (Diag. 2). In this status, the number of fractures that can occur plane failure is 32, wedge failure is 45 and toppling failure is 21.

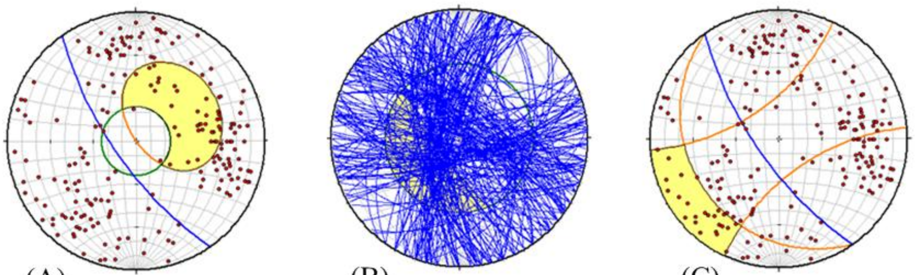


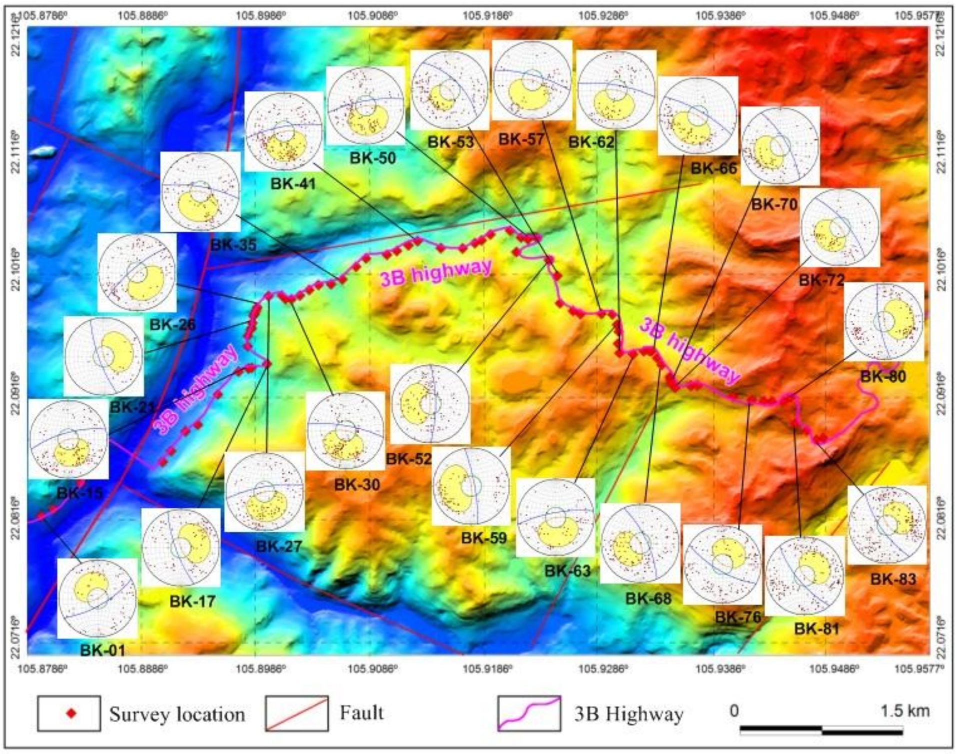
Diagram (3): The analytical results according to Hoek and Bray's application (2004) at the survey site BK-82; (A) Plane failure, (B) Wedge failure, (C) Toppling failure.

Similarly, the analysis is also considered for total other survey sites along the 3B highway in Xuathoa area, Backan province, Vietnam (Maps: 2-4 and Tabs: 2-4).

Plane failure

Table (2): The statistical results of the number and percentage of fractures at the survey sites can occur plane failure along the 3B highway in Xuathoa area, Backan province, Vietnam.

No.	Survey sites	Number	Percentage (%)	No.	Survey sites	Number	Percentage (%)
1	BK-01	8	10.96	18	BK-61	7	4.24
2	BK-15	35	27.56	19	BK-62	23	30.26
3	BK-17	18	17.48	20	BK-63	14	21.54
4	BK-21	5	21.74	21	BK-66	34	32.69
5	BK-26	7	6.03	22	BK-68	29	24.17
6	BK-27	43	35.25	23	BK-69	21	20.39
7	BK-28	18	18.75	24	BK-72	32	45.71
8	BK-30	57	41.61	25	BK-74	18	15.13
9	BK-34	18	18.75	26	BK-75	19	19.19
10	BK-35	25	23.81	27	BK-76	14	10.94
11	BK-41	69	36.70	28	BK-78	45	29.61
12	BK-50	45	33.09	29	BK-79	13	8.39
13	BK-52	29	25.66	30	BK-80	29	18.35
14	BK-53	19	14.07	31	BK-81	16	9.30
15	BK-57	13	18.31	32	BK-82	32	14.88
16	BK-58	24	26.67	33	BK-83	10	9.80
17	BK-59	33	41.77				



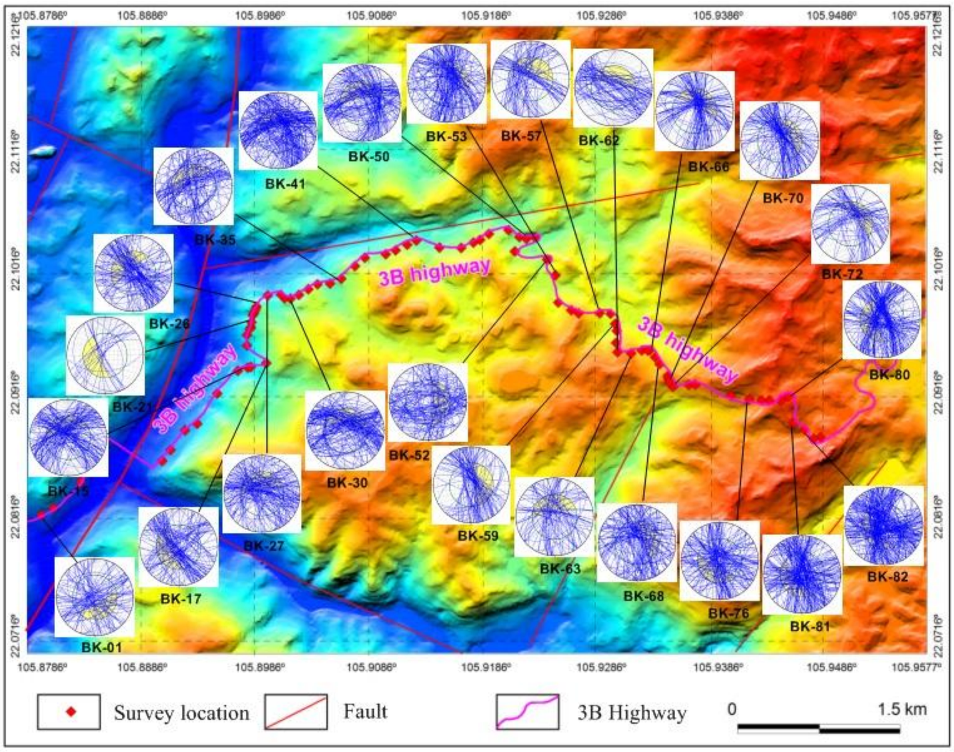
Map (2): The survey sites can occur plane failure according to analyzing fracture orientations along the 3B highway in Xuathoa area, Backan province, Vietnam.

Wedge failure

Table (3): The statistical results of the number and percentage of fractures at the survey sites can occur wedge failure along the 3B highway in Xuathoa area, Backan province, Vietnam.

No.	Survey sites	Number	Percentage (%)	No.	Survey sites	Number	Percentage (%)
1	BK-01	5	6.85	18	BK-61	51	30.91
2	BK-15	9	7.09	19	BK-62	0	0.00
3	BK-17	4	3.88	20	BK-63	35	53.85
4	BK-21	6	26.09	21	BK-66	40	38.46
5	BK-26	7	6.03	22	BK-68	50	41.67
6	BK-27	24	19.67	23	BK-69	9	8.74
7	BK-28	10	10.42	24	BK-72	28	40.00
8	BK-30	19	13.87	25	BK-74	16	13.45
9	BK-34	6	6.25	26	BK-75	39	39.39
10	BK-35	20	19.05	27	BK-76	39	30.47
11	BK-41	52	27.66	28	BK-78	24	15.79
12	BK-50	8	5.88	29	BK-79	29	18.71
13	BK-52	56	49.56	30	BK-80	58	36.71
14	BK-53	55	40.74	31	BK-81	27	15.70

15	BK-57	44	61.97	32	BK-82	45	20.93
16	BK-58	07	7.78	33	BK-83	20	19.61
17	BK-59	14	17.72				



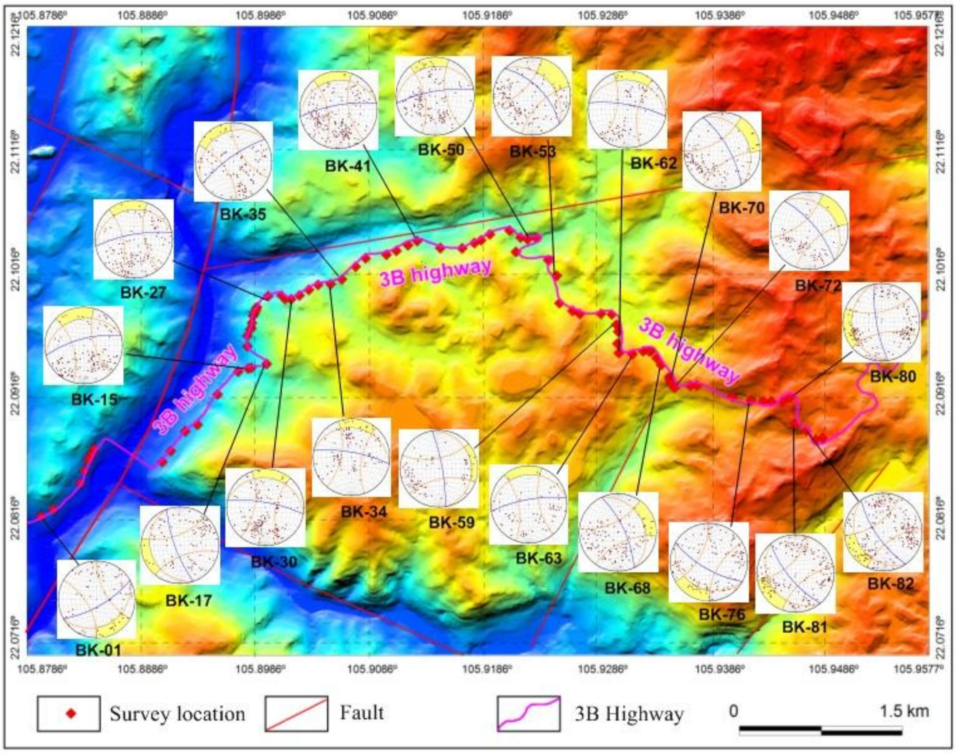
Map (3): The survey sites can occur wedge failure according to analyzing fracture orientations along the 3B highway in Xuathoa area, Backan province, Vietnam.

Toppling failure

Table (4): The statistical results of the number and percentage of fractures at the survey sites can occur toppling failure along the 3B highway in Xuathoa area, Backan province, Vietnam.

No.	Survey sites	Number	Percentage (%)	No.	Survey sites	Number	Percentage (%)
1	BK-01	13	17.81	18	BK-61	7	4.24
2	BK-15	5	3.94	19	BK-62	6	7.89
3	BK-17	4	3.88	20	BK-63	3	4.62
4	BK-21	0	0.00	21	BK-66	0	0.00
5	BK-26	1	0.86	22	BK-68	10	8.33
6	BK-27	3	2.46	23	BK-69	6	5.83
7	BK-28	5	5.21	24	BK-72	2	2.86
8	BK-30	4	2.92	25	BK-74	4	3.36
9	BK-34	9	9.38	26	BK-75	10	10.10
10	BK-35	7	6.67	27	BK-76	12	9.38

11	BK-41	2	1.06	28	BK-78	09	5.92
12	BK-50	10	7.35	29	BK-79	17	10.97
13	BK-52	1	0.88	30	BK-80	20	12.66
14	BK-53	7	5.19	31	BK-81	20	11.63
15	BK-57	1	1.41	32	BK-82	21	9.77
16	BK-58	7	7.78	33	BK-83	14	13.73
17	BK-59	5	6.33				



Map (4): The survey sites can occur toppling failure according to fracture orientations along the 3B highway in Xuathoa area, Backan province, Vietnam.

The analytical results of percentage of plane failure, wedge failure and toppling failure in the Tables 2 to 4 are plotted in Diagram (3).

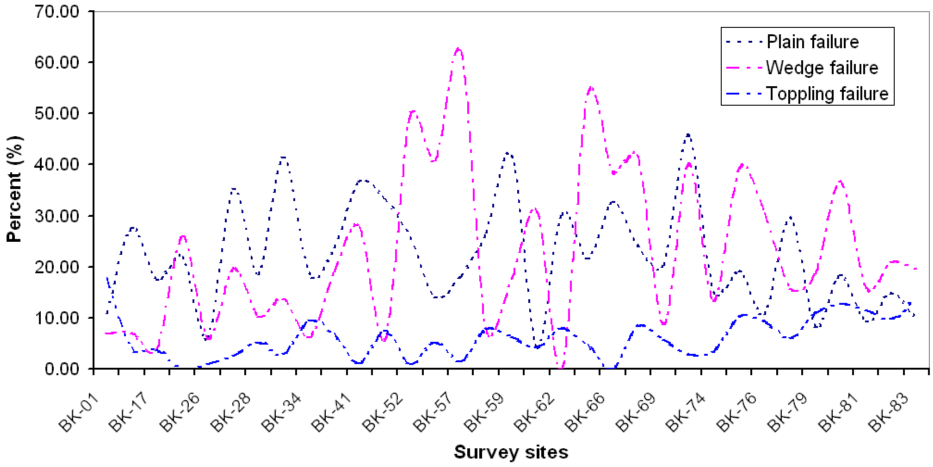


Diagram (3): The graph of fracture percentage can occur the plane failure, wedge failure and toppling failure at each survey site along the 3B highway in Xuathoa area, Backan province, Vietnam.

The slope failure analysis is conducted based on the statistical percentage of fracture orientations which can occur the plane failure, wedge and toppling failure at each survey site along the 3B highway in Xuathoa area, Backan province, Vietnam. In Diagram (3), the fracture percentage lies within the region that can occur the plane failure varies slightly among the survey sites; the largest percentage value belongs to the survey sites: BK-27, BK-30, BK-41, BK-59, BK-72 and BK-78.

Similarly, the intersection percentage of the conjugate fractures lies within the region that can occur the wedge failure varies slightly from survey sites BK-01 to BK-50, from BK-72 to BK-83 and the largest change at the survey sites: BK-52, BK-53, BK-57, BK-63, BK-66, BK-72, BK-75, BK-80; the fracture percentage lies within the region can occur the toppling failure varies slightly at total survey sites along the 3B highway in Xuathoa area, Backan province. The comparison results among the three types of failures in Diagram (3) indicate that the survey sites from BK-01 to BK-50 and from the survey sites BK-69 to BK-83, the fractures can occur plane failure and wedge failure together.

However, the fracture percentage can occur the wedge failure is smaller than the fracture percentage that can occurs the plane failure, particularly for the survey sites from BK-78 to BK-83, the plane failure, wedge failure and toppling failure can occur together.

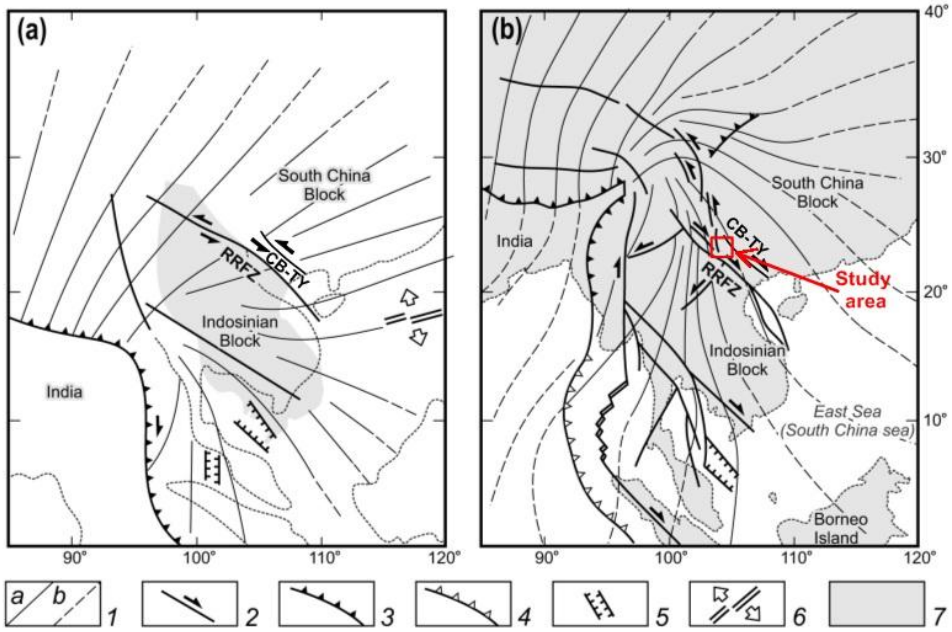
Discussion

The 3B highway belongs to Xuathoa area, Backan province, Vietnam cut through the ancient rock of the Devon system with the main component is marlaceous shale (Nguyen *et al.*, 2000). These rocks were severely broken due to the tectonic activities of the Indian-Australian Plate move toward the north and the Pacific Plate move toward the west, forming the compressed and extended area (Phung *et al.*, 1996). Some the other research results suggested that the northeastern region of Vietnam, including the 3B highway in Xuathoa area, Backan province (Map 5) occurs two major phases of tectonic activity in the Cenozoic era (Nguyen, 1991; Phung *et al.*, 1996). The early phase was determined as occurrence from Eocene to late Miocene period and late phase occurs during the Pliocene - Quaternary period (Vu, 2002). The first tectonic phase caused the left-lateral motion of the NW-SE fault system and the late phase caused the right-lateral motion of this fault system.

The left-lateral motion of the Red River Fault System was the results of the India-Eurasia plate collision (Tapponnier *et al*.,1986) and it occurred during within 30 Ma to 5.5 Ma, corresponding to the Oligocene-Miocene period, from analytical results of the seismic data (Rangin *et al*., 1995). The another analytical result of seismic profiles in the north area of the Red River sedimentary basin also identified one phase of left-lateral motion that occurred about before 21 Ma within the Song Lo and Song Chay river fault zone, belong to the Red River Fault System (Nguyen, 2003). Besides, the study also indicated one different tectonic activity phase with the NE-SW compression direction, caused the inversion of NW-SE trending fault during 10.5 k.y - 5.5 k.y. In addition, the analyzing geological structure of Oligocene sedimentary rocks on Bach Long Vi island also determined three maximum compression phases: E-W, NE-SW and NW-SE during the Cenozoic era (Phung *et al*., 2007). Recently, the analyzing tributaries of the Red River Fault System from Quaternary alluvial fans, river valley on Landsat and SPOT satellite images, detailed topographical maps and field observation determined right-lateral offsets of stream channels range between 150 and 700m (Phan *et al.*, 2012). This is the results of the stress state of N-S compression direction; E-W extension direction caused the right lateral strike-slip along the Red River Fault System and probably, began in the Pliocene time. The tectonic phase also was clearly visible on the Red River Fault System and the Dien Bien Phu fault from the analyses of Landsat and SPOT satellite images (Lacassin *et al.,* 1994; Phan *et al.,* 2012).

The Phan *et al*. (2012) analyses also recognized that Cao Bang - Tien Yen (CB-TY) fault which is located in the NE of the Red River Fault System is right lateral strike-slip fault, results from the N-S compression direction using Landsat and SPOT satellite images, aerophotographs and 1:50.000 scale topographic maps. The relation to dextral strike-slip motion of the Red River Fault System in the episode of Pliocene-Quaternary also confirmed in study of Witold (2013). The result of tectonic-geomorphic studies indicated that the amount of Quaternary dextral offset of the Red River Fault System in Vietnam, calculated from offset and deflection of the tributary valleys of the Red River, ranges between 400m and 5.3km. The axis of maximum horizontal compression associated with dextral slip of the fault zone were aligned from NNW-SSE to N-S.

Similarly, the Kasatkin *et al.* (2014)'s study indicated that predominantly sinistral strike slip of Red River Fault System formed as a result of ENE regional compression (80°) during the Oligocene-Miocene period and dextral strike slip of the Red River Fault System formed as a result of NNW regional compression 330-350° during the Pliocene-Quaternary.



Map (5): Trajectories of the maximum compressive stress within the Indochina Peninsula during the Oligocene (a) and at the present time (b). The legend in the Map (5) is described as follows: (1) trajectories of the maximum compressive stress are directly related to the Indo-Eurasian plate collision (a) and its far-field effects (b); (2) faults and directions of displacement (arrows); (3) zone of continental collision; (4) subduction zone; (5) extension structures; (6) spreading zones; (7) current position of the land; Red River Fault System (RRFS); Cao Bang - Tien Yen fault (CB-TY) (Kasatkin *et al*., 2014).

The failure blocks on rock slope surfaces are formed by the intersection of fractures, faults in different directions and rock slope surfaces. The fractures, faults are the result of tectonic activities in the earth's crust. Initially, the rock blocks are formed by the intersection among fractures in steady status; after being excavated, they lose their equilibrium status and can slide on the rock slope surface, causing plane failure, wedge failure or toppling failure.

The statistical data in the study area showed that the fracture orientations, which collected at survey sites developed in three main directions: E-W, NW-SE, N-S (Diag. 4).

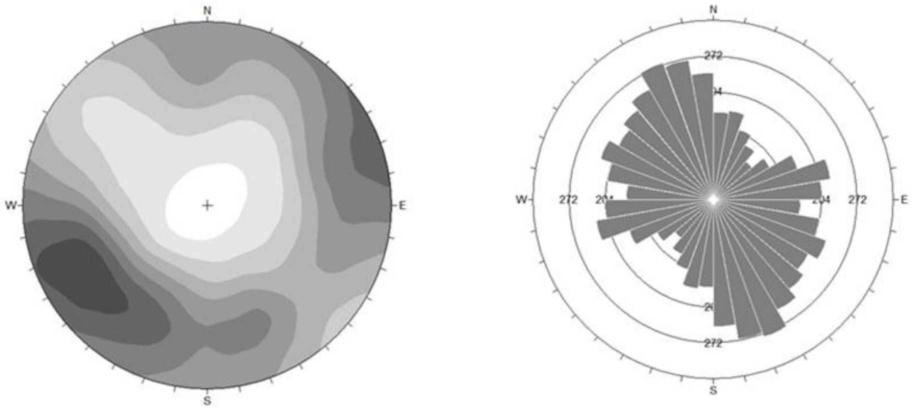


Diagram (4): The contour graph and rose graph of 3813 fractures at 33 survey sites along 3B highway in Xuathoa, Backan province, Vietnam.

The percentage value of fracture direction of the total survey sites is recorded in Table (5) and Diagram (5).

Table (5): The percentage value of the fracture direction at the total survey sites along 3B highway in Xuathoa area, Backan province, Vietnam.

No	Orientation (Degree)	Percentage (%)	No	Orientation (Degree)	Percentage (%)
1	0-10	4.38	10	271-280	6.08
2	11-20	5.51	11	281-290	6.03
3	21-30	3.80	12	291-300	6.43
4	31-40	3.25	13	301-310	6.06
5	41-50	3.38	14	311-320	5.80
6	51-60	4.20	15	321-330	6.71
7	61-70	5.61	16	331-340	7.79
8	71-80	6.48	17	341-350	7.87
9	81-90	4.67	18	351-360	5.95

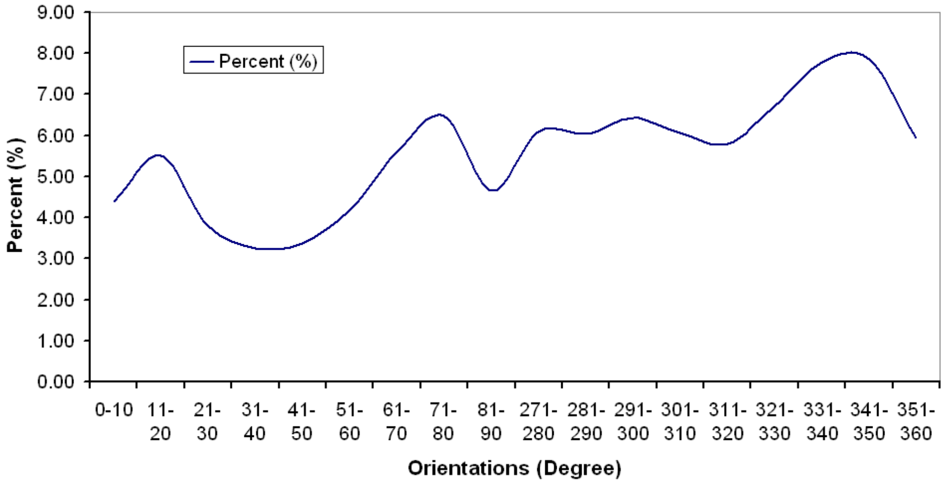


Diagram (5): The graph of percentage value of the fracture direction of the total survey sites along 3B highway in Xuathoa area, Backan province, Vietnam.

The intersection of the different fracture orientations and the slope surface along the 3B highway in Xuathoa area, Backan province, Vietnam have formed a series of blocks that can occur plane failure, wedge failure and toppling failure. In the direction of E-W, the survey sites BK-27, BK-30, BK-41, BK-59 và BK-72 clearly reflect that high plane failure potential may occur in the E-W orientation fracture system; in the direction of NW-SE, the survey sites BK-52, BK-53, BK-57, BK-63, BK-66, BK- 68, BK-72, BK-75, BK-80 clearly reflect that the high wedge failure potential can occur in the NW-SE orientation fracture system. The analytical results of this study also indicate the relationship between the fracture orientation, which formed due to the tectonic activity and the direction of the rock slope surface and the formation of the types of failure blocks.

CONCLUSIONS

By analyzing 3813 fracture orientations at 33 survey sites on the marlaceous shale belong Devon formation, along the 3B highway in Xuathoa area, Backan province, Vietnam, the analytical results have also indicated that the phenomena of plane failure, wedge failure and toppling failure can occur at almost survey sites within the study area.

The statistical data also show that the fracture orientation mainly develop in the E-W, N-S and NW-SE due to the influence of tectonic activity; the occurrence of them together with the rock slope surface direction has formed the type of plane failure for the 3B highway in the E-W direction and the type of wedge failure and some toppling failure for the 3B highway in the N-S and NW-SE direction. The results of this study have important significance in planning the highway design and tunnel construction; because, this way will be excavating in the next time.

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فشل بلوكات المنحدر الصخري وعلاقتها بالفعالية البنائية التكتونية : دراسة للطريق السريع ب3 منطقة كزاثوا ، مقاطعة باكان ، فيتنام

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الخلاصة

يعرض البحث نتائج تحاليل فشل الميل من توزيعات الكسر وعلاقتها بالنشاط التكتوني؛ وقد أشارت النتائج التحليلية إلى أن ظواهر الفشل بالمستوى الافقي والعمودي والإخفاق في الانقلاب يمكن أن تحدث في مواقع المسح تقريباً داخل منطقة الدراسة للطريق السريع ب3 منطقة كزاثوا ، مقاطعة باكان ، فيتنام.

تشير البيانات الإحصائية إلى أن اتجاه الكسر يتطور بشكل أساسي باتجاه شرق – غرب و باتجاهات شمال –جنوب و شمال غربي- جنوب شرقي.

تحدث ظواهر الفشل الثلاثة بسبب تأثير النشاط التكتوني البنائي للقشرة الارضية مع اتجاه سطح الانحدار الصخري بتكوين مستوى ضعف وفشل على سطح المنحدر للطريع السريع 3ب باتجاه شرق – غرب، و بانواع فشل عمودية وتدية ومنقلبة على سطح المنحني للطريق السريع باتجاهات شمال –جنوب و شمال غربي- جنوب شرقي.