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SOME ANALYTICAL RESULTS OF ROCK SLOPE SURFACE STABILITY ON THE ROAD AROUND THE HON NGANG ISLAND IN KIEN HAI DISTRICT, KIEN GIANG PROVINCE, VIETNAM

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Abstract

This paper presents the results of rock slope surface stability analyses using the application of Hoek and Bray (2004) and Block Theory of Goodman and Shi (1995) from 834 fracture orientation measurements of the ten rock slope surfaces along the road, cut through the volcanic rocks of Hon Ngang formation, around the Hon Ngang island, Kien Hai district, Kien Giang province, Vietnam. The analytical results have been determined, the average percentage of plane failure can occur on the total rock slope surfaces is the largest, namely the average percentage of plane failure is 18.41%, the wedge failure is 9.65% and the toppling failure is 9.98%. Because the road is excavated around the island, the direction of the rock slope surfaces is also varied accordingly. The analytical results of the rock slope surface stability in different directions of the road are determined: the average value of fractures in the direction N - S, dip to W for plane failure is 17.48%, wedge failure is 10.85%, and toppling failure is 5.65%; the average value of fractures in the direction N - S, dip to E for plane failure is 22.69%, wedge failure is 13.01% and toppling failure is 10.78%; the average value of fractures in the direction NWW - SEE, dip to NEN for plane failure is 21.41%, wedge failure is 10.17% and toppling failure is 11.72%; the average value of fractures in the direction E - W, dip to S for plane failure is 12.76%, wedge failure is 5.13% and toppling failure is 10.91%. Besides, the analytical results have also identified five rock slope surfaces which appear key blocks: HN-01 (key block 129º/24º); HN-04 (key block 070º/33º); HN-11 (key block 035º/70º); HN-13 (key block 079º/36º); HN-14 (key block 122º/35º). These results have also shown that the existence of key blocks on the rock slope surface in the N - S direction, dip to E at the survey locations HN-1, 13 and 14; and the rock slope surface in the NWW - SEE direction, dip to NEN at the survey locations HN-4 and 11. These results have important significance to support for protecting slope surface safety.

Keywords: Rock slope; Key block; Plane failure; Wedge failure; Toppling failure.

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1. Introduction

Hon Ngang island is the second-largest island in the Nam Du archipelago, which is located in the Gulf of Thailand, southwest of Vietnam (Fig. 1).

The island has an area of about 1 km^2 and a population of over 2000 people. Due to the travel needs of the people and economic development, the road around the Hon Ngang island has been excavated. The road cut through the volcanic rocks of the Hon Ngang formation. The slope failure potential can occur (Fig. 2). To ensure the safety of the people and tourists visiting the island, the study of rock slope surfaces stability is very essential.

The studies of rock slope surface stability have been conducted since the 1980s of the last century: Goodman and Shi (1985) [3] for potential key block analysis; Hoek and Bray (2004) [4] for kinematic analysis of the rock slope stability.

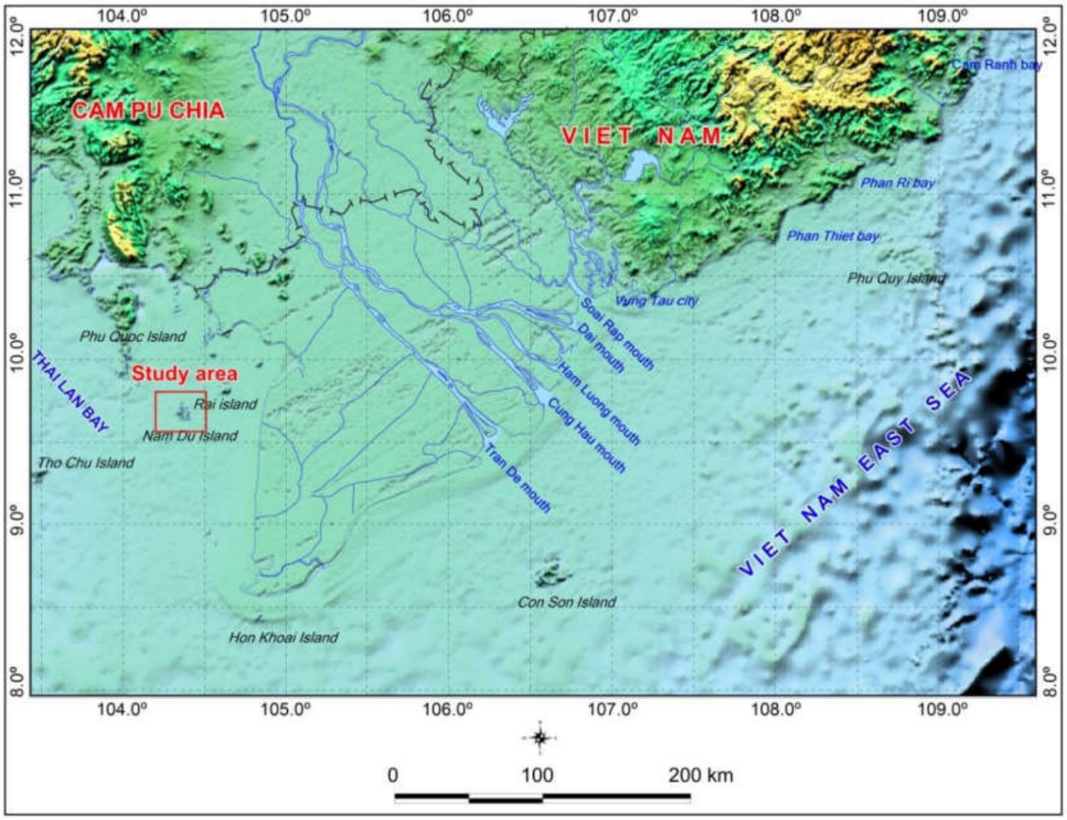


Figure 1: Location map of Hon Ngang island in the Nam Du archipelago

Figure 2: Slope failure potential on the Hon Lon island, belong to the Nam Du archipelago

The analytical approach of Hoek and Bray (2004) [4] has been used effectively in many projects of identifying the types of plane failure, wedge failure, toppling failure on the rock slope surface. Olaleye et al. (2011) [9] analyzed kinematics of planar discontinuity sets using DIPS software in a limestone deposit in Western Nigeria and have indicated the percentage risk of plane failure, wedge failure and toppling failure. By using the stereographic projection from DIPS software to analyze detailed slope stability for selecting the slope sites along Katas-Choa Saiden Shah road, Danish (2015) [1] has also determined the risk level of plane failure and toppling failure for each slope surface. Recently, Mithresh KP et al. (2017) [6] analyzed kinematic of rock slope from discontinuity orientation, like joints, faults, bedding plane,...and indicated the joint sets can occur wedge failure and plane failure. Last year, Truong Thanh Phi et al., (2018) [10] have used Hoek and Bray (2004)'s application to analyze the rock block failure modes and the relationship between them and tectonic activities along the 3B highway to support for designing the proposed 3B highway, Xuat Hoa area, Bac Kan province, Vietnam and Truong Thanh Phi (2019) [11] has also used this application to analyze rock slope failure of a limestone block and created them in three dimensions (3D) in Ha Long Bay, a World Natural Heritage, Quang Ninh province, Vietnam.

Parallel to the above approach, the key block analysis of Block Theory, method of Goodman and Shi (1985) [3] have also high utility and similar effects. The Block Theory method of Goodman and Shi (1985) [3] 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 key blocks. Therefore, the key block analysis has been receiving a lot of attention among engineers because in actual engineering projects, it loses its stability first after excavation. Um and Kulatilake (2001) [12] 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. Based 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. In the next years, Quoc Phi Nguyen (2009) [7] used Block Theory method of Goodman and Shi (1985) [3] to identify the potential keyblocks along the Bong Hwang tunnel, South Korea. Then, the obtained results have examined using ROCK3D software. Quoc Phi Nguyen and Truong Thanh Phi (2014) [8] applied the Block Theory method to find potential failure along road 6, belong 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 using Block Theory of Goodman and Shi (1985) [3], the rock slope stability analysis of Hoek and Bray (2004) to assess the rock slope surface stability on the road around the Hon Ngang island, Kien Hai district, Kien Giang province, Vietnam.

2. Materials and methods

2.1. Materials

Data sources used in this study are the fracture orientations, which were selected from 20 survey locations on the rock slope surface along the road around the Hon Ngang island, belonging to the Nam Du archipelago, Kien Hai district, Kien Giang province, Vietnam. The collected data was measured randomly using a compass at each survey location (Fig. 3 and Tab. 1).

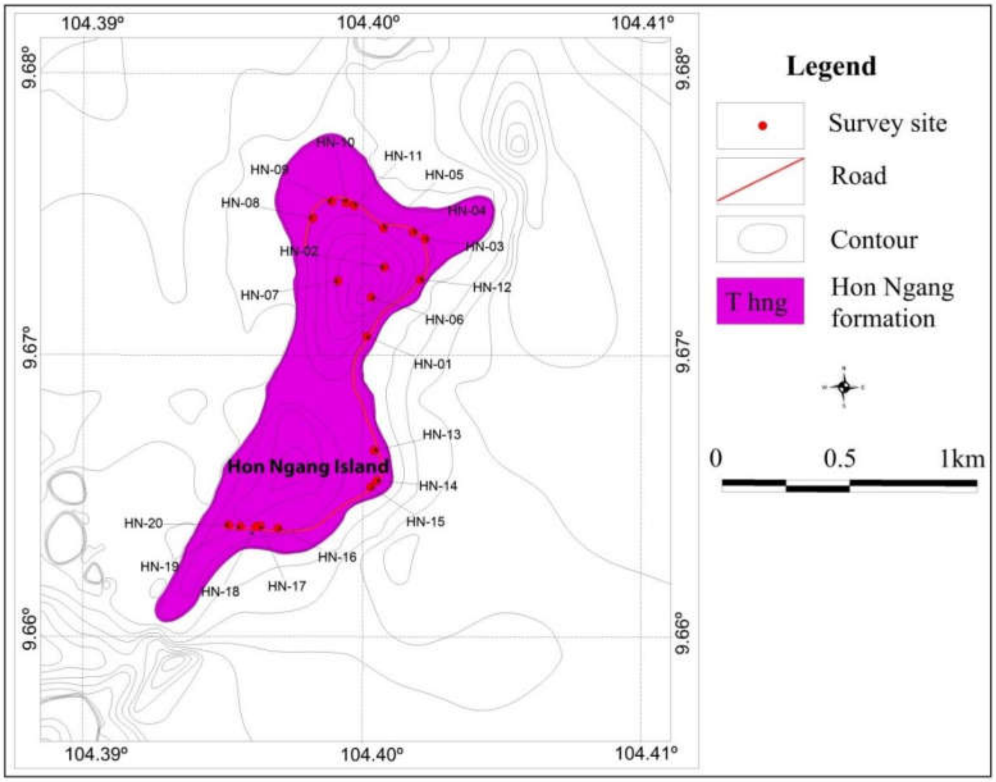


Figure 3: Geological map, minimized from scale 1: 50.000 and survey locations

The Hon Ngang formation (T *hng*) includes rhyolite, altered felsic effusive rocks, and their tuffs, tuffaceous sandstone, shale with a thickness of 500 m.

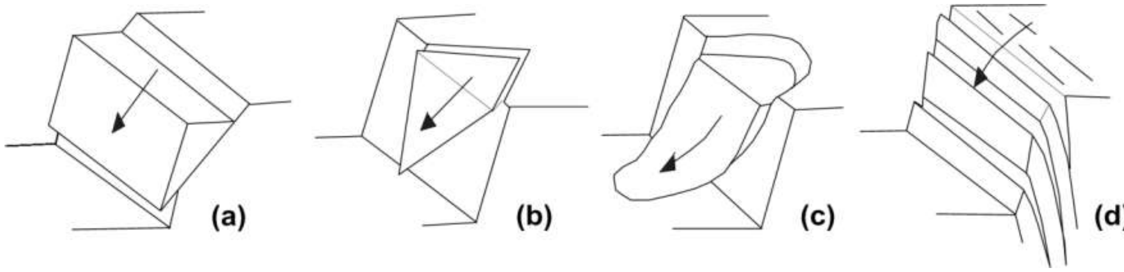
Table 1. The survey locations, rock slope surface orientation and fracture number

No	Survey locations	Longitude	Latitude	Slope surface orientation	Fracture number	Geological age
1	HN-01	104.400159°	9.670687°	100°/70°	90	T *hng*
2	HN-03	104.402259°	9.674153°	265°/70°	105	T *hng*
3	HN-04	104.401826°	9.674387°	030°/70°	102	T *hng*
4	HN-07	104.399126°	9.672653°	280°/70°	107	T *hng*
5	HN-11	104.399703°	9.675327°	035°/70°	88	T *hng*
6	HN-13	104.400442°	9.666620°	075°/70°	64	T *hng*
7	HN-14	104.400526°	9.665553°	110°/70°	65	T *hng*
8	HN-16	104.396992°	9.663853°	170°/70°	36	T *hng*
9	HN-18	104.396192°	9.663903°	190°/70°	76	T *hng*
10	HN-20	104.395226°	9.663970°	195°/70°	102	T *hng*

2.2. Methods

Rock slope failure analysis

The analyses of plane failure, wedge failure, toppling failure and circular failure were carried out by Hoek and Bray (2004)'s application, based on the fracture orientation in three-dimensional space. The analytical results will be identified as the types of plane failure, wedge failure, toppling, and circular failure on the rock slope surface as shown in Figs. 4 and 5.



a) Plane failure, the fracture orientation is sub-parallel to slope surface;

b) Wedge failure, which slides on the intersection of two fracture surfaces;

c) The circular failure in the weak rock, with the random fracture orientation;

d) Toppling failure occurs in hard rock that has the fracture surface which is inclined to slope surface.

Figure 4: Pattern of failure modes on the rock slope surface (Hoek and Bray, 2004) [4]

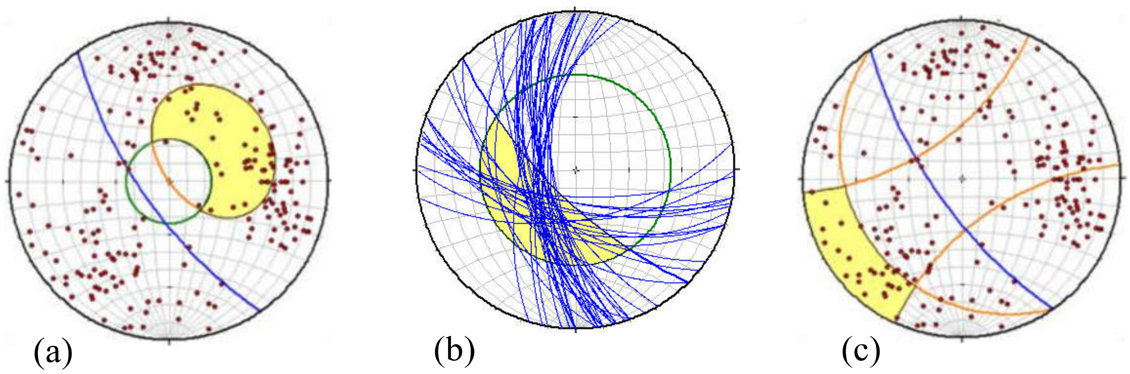


Figure 5: a) Plane failure, b) wedge failure and c) toppling failure (according to Hoek and Bray, 2004) [4]

Keyblock potential analysis

According to Block Theory method of Goodman and Shi (1985), the space above 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:

$$BP = JP \cap EP \qquad (1)$$

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

A block is finite if and only if

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

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.

$$JP \subset SP \qquad (3)$$

In Figure 6, a lower-focal-point stereographic projection of four joint sets and a free plane (plane 5). Assuming that the rock mass is below plane 5, SP is the area inside the great circle for plane 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.

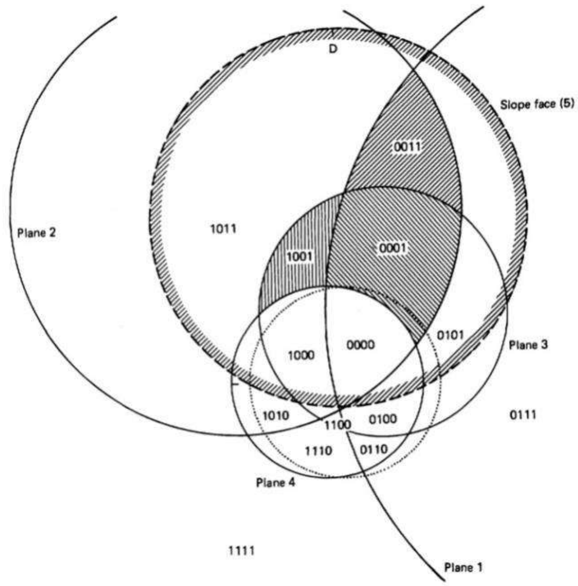


Figure 6: Stereonet projection of data of 1) joint set (080º/75º); 2) joint set (330º/65º); 3) joint set (030º/40º); 4) joint set (270º/10º); 5) free surface (000º/60º) with the free surface of plane 5 only (Goodman and Shi, 1985) [3]

3. Analytical results

3.1. Slope failure analysis

The rock slope stability analyses are conducted from 834 fracture orientation measurements of ten rock slope surfaces from 20 survey locations along the road around the Hon Ngang island with a length of about 2.5 km, cut through volcanic rocks of the Hon Ngang formation. The slope stability analysis is conducted according to Hoek and Bray 2004's application with the friction angle ϕ = 50º for volcanic rock. The analytical results for plane failure, wedge failure and toppling failure are plotted in Fig. 7 - 9.

Plane failure

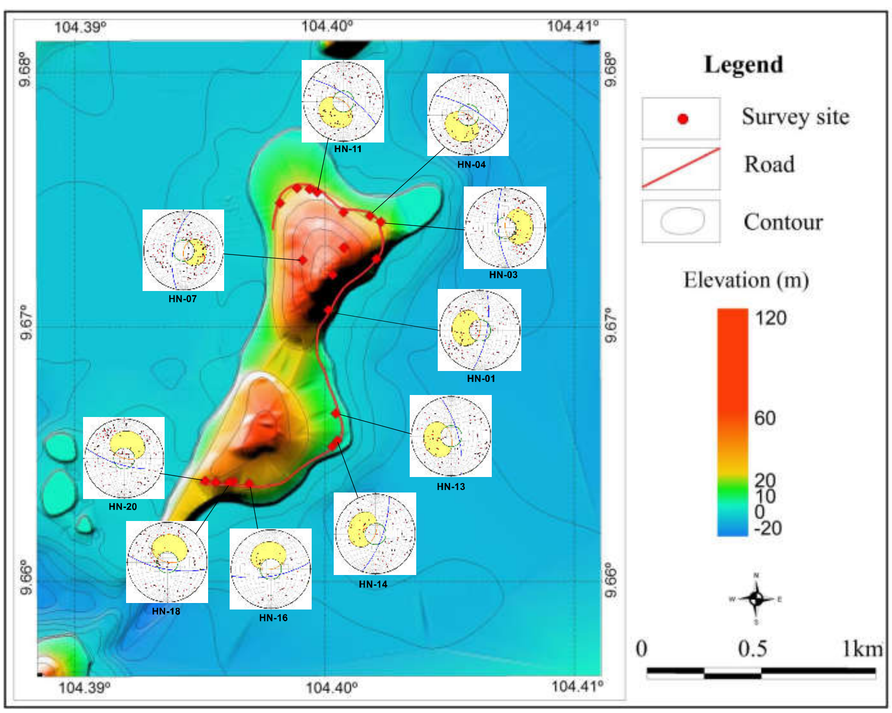


Figure 7: Plane failure on the rock slope surface around the Hon Ngang island

The analytical results of the fracture number which can occur the plane failure at ten rock slope surfaces along the road around the Hon Ngang island in Fig. 7 are recorded in Tab. 2.

Table 2. Statistical percentage of the fracture number which can occur plane failure at ten rock slope surfaces around the Hon Ngang island

No	Survey locations	Fracture number can occur plane failure	Percentage (%)	No	Survey locations	Fracture number can occur plane failure	Percentage (%)
1	HN-01	18/90	20.00	6	HN-13	16/64	25.00
2	HN-03	22/105	20.95	7	HN-14	15/65	23.08
3	HN-04	17/102	16.67	8	HN-16	10/36	27.78
4	HN-07	15/107	14.02	9	HN-18	5/76	6.58
5	HN - 11	23/88	26.14	10	HN-20	4/102	3.92

In Tab. 2, the percentage of the fracture number which can occur plane failure at each rock slope surface is calculated by the fracture number which can occur plane failure divided by the total fracture number measured at each rock slope surface.

Wedge failure

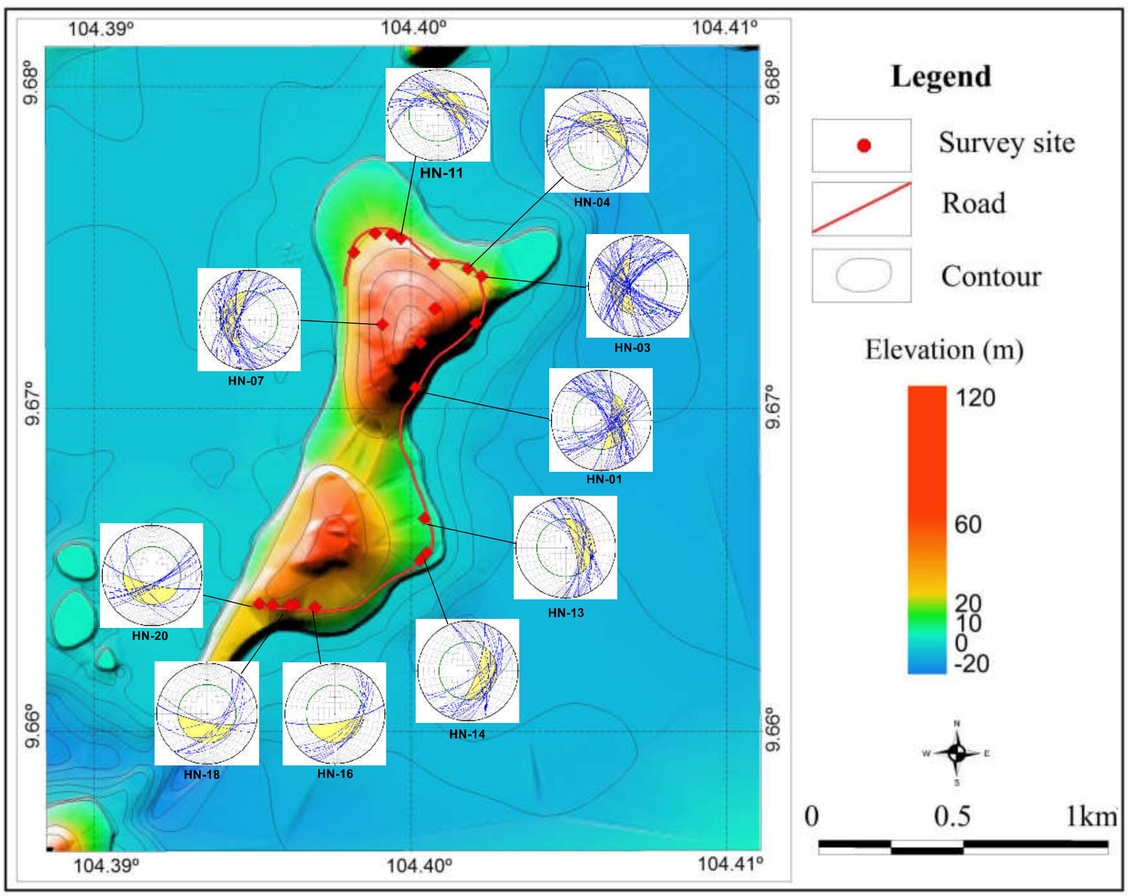


Figure 8: Wedge failure on the rock slope surface around the Hon Ngang island

The analytical results of the fracture number which can occur the wedge failure at ten rock slope surfaces along the road around the Hon Ngang island in Fig. 8 are recorded in Tab. 3.

Table 3. Statistical percentage of the fracture number which can occur wedge failure at ten rock slope surfaces around the Hon Ngang island

No	Survey locations	Fracture number can occur wedge failure	Percentage (%)	No	Survey locations	Fracture number can occur wedge failure	Percentage (%)
1	HN-01	17/90	18.89	6	HN-13	6/64	9.38
2	HN-03	11/105	10.48	7	HN-14	7/65	10.77
3	HN-04	8/102	7.84	8	HN-16	0/36	0.00
4	HN-07	12/107	11.21	9	HN-18	5/76	6.58
5	HN-11	11/88	12.50	10	HN-20	9/102	8.82

Similar to Tab. 2, in Tab. 3, the percentage of the fracture number which can occur wedge failure at each rock slope surface is calculated by the fracture number which can occur wedge failure divided by the total fracture number measured at each rock slope surface.

Toppling failure

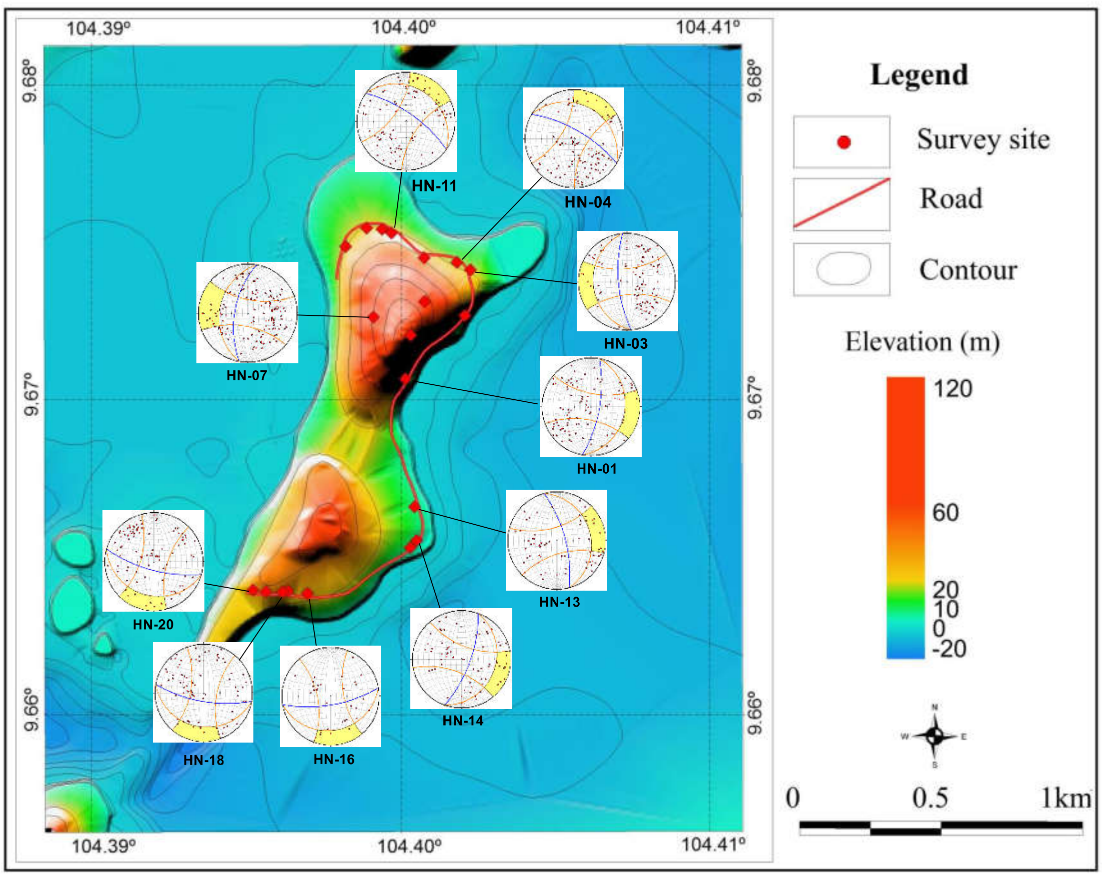


Figure 9: Toppling failure on the rock slope surface around the Hon Ngang island

The analytical results of the fracture number which can occur the toppling failure at ten rock slope surfaces along the road around the Hon Ngang island in Fig. 9 are recorded in Tab. 4.

Table 4. Statistical percentage of the fracture number which can occur toppling failure at ten rock slope surfaces around the Hon Ngang island

No	Survey locations	Fracture number can occur toppling failure	Percentage (%)	No	Survey locations	Fracture number can occur toppling failure	Percentage (%)
1	HN-01	4/90	4.44	6	HN-13	9/64	14.06
2	HN- 03	4/105	3.81	7	HN-14	9/65	13.85
3	HN-04	10/102	9.80	8	HN-16	6/36	16.67
4	HN-07	8/107	7.48	9	HN-18	7/76	9.21
5	HN-11	12/88	13.64	10	HN-20	7/102	6.86

In Table 4, the percentage of the fracture number that can occur toppling failure at each rock slope surface is calculated by the fracture number that can occur toppling failure divided by the total fracture number measured at each rock slope surface.

Because the road is excavated around the island, the direction of the slope surface also changes (N - S, E - W, NWW - SEE). The average values of the plane failure, wedge failure and toppling failure on rock slope surface are shown in Tab. 5.

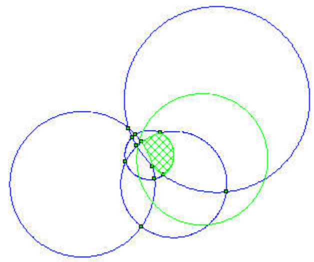
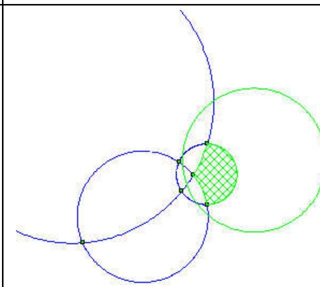
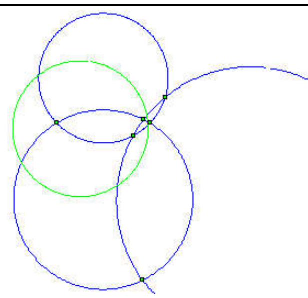
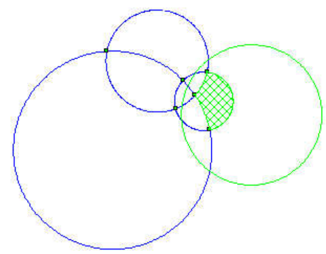
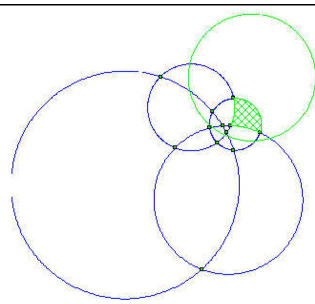
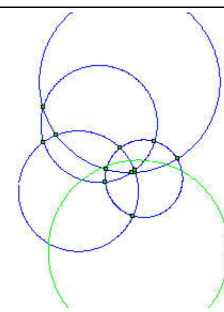
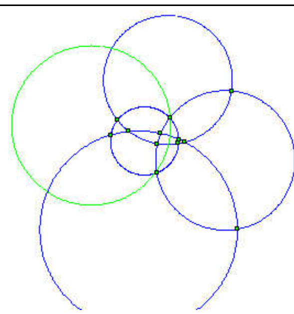
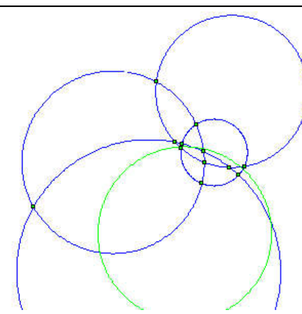
Table 5. The average percentage of the fracture number that can occur the plane failure, wedge failure and toppling failure on the rock slope surfaces in the directions: N - S, N - S, E - W, NWW - SEE around the Hon Ngang island

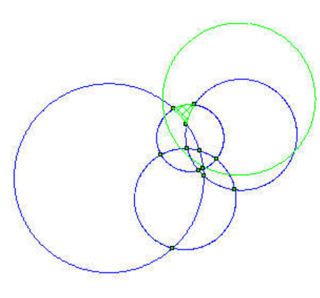
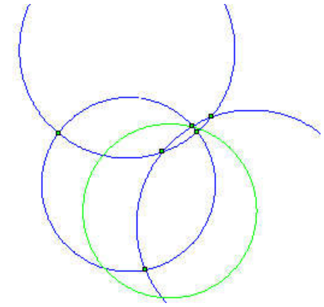
Nº	Survey index	Plane failure	Wedge failure	Toppling failure	Orien-tation/ dip	Nº	Survey index	Plane failure	Wedge failure	Toppling failure	Orien-tation/ dip
1	HN-07	14.02	11.21	7.48	N - S/W	3	HN-04	16.67	7.84	9.8	NWW - SEE/ NEN
	HN-03	20.95	10.48	3.81	N - S/W		HN-11	26.14	12.5	13.64	NWW - SEE/ NEN
Average		**17.48**	**10.85**	**5.65**	**N - S/W**	**Average**		**21.405**	**10.17**	**11.72**	**NWW - SEE/ NEN**
2	HN-13	25	9.38	14.06	N - S/E	4	HN-16	27.78	0	16.67	E - W/S
	HN-14	23.08	10.77	13.85	N - S/E		HN-18	6.58	6.58	9.21	E - W/S
	HN-01	20	18.89	4.44	N - S/E		HN-20	3.92	8.82	6.86	E - W/S
Average		**22.69**	**13.01**	**10.78**	**N - S/E**	**Average**		**12.76**	**5.13**	**10.91**	**E - W/S**

3.2. Keyblock potential analysis

The keyblock analysis is carried out on each rock slope surface according to the fracture orientation measurements by using the Block Theory analysis of Goodman and Shi (1985) [3]. The analytical results are shown in Tab. 6.

Table 6. Keyblock analysis from fracture sets at each slope around the Hon Ngang island

Index	Fracture set(DD/DA*)	Keyblock	Index	Fracture set(DD/DA*)	Keyblock
HN-01	$057^o/76^o$; $138^o/65^o$; $239^o/72^o$; $129^o/24^o$	 Key block $129^o/24^o$ (0010)	HN-13	$303^o/80^o$; $230^o/68^o$; $079^o/36^o$	 Key block $079^o/36^o$ (110)
HN-03	$318^o/69^o$; $208^o/75^o$; $126^o/80^o$	 None keyblock	HN-14	$122^o/35^o$; $223^o/76^o$; $314^o/62^o$	 Key block $122^o/35^o$ (011)
HN-04	$305^o/60^o$; $240^o/79^o$; $175^o/73^o$; $070^o/33^o$	 Key block $070^o/33^o$ (1110)	HN-16	$120^o/37^o$; $004^o/70^o$; $242^o/59^o$; $330^o/58^o$	 None keyblock
HN-07	$196^o/74^o$; $263^o/37^o$; $003^o/65^o$; $110^o/67^o$	 None keyblock	HN-18	$203^o/77^o$; $087^o/27^o$; $028^o/67^o$; $264^o/71^o$	 None keyblock

HN-11	257°/74°; 197°/59°; 060°/62°; 339°/39°	 Key block 035°/70° (1110)	HN-20	147°/75°; 230°/70°; 322°/74°	 None keyblock

*DD: Dip Direction; DA: Dip Angle

Tab. 6 indicates that five-rock slope surfaces have occurred keyblocks: HN-01 (Keyblock 129°/24°), HN-04 (Keyblock 070°/33°), HN-11 (Keyblock 035°/70°), HN-13 (Keyblock 079°/36°), HN-14 (Keyblock 122°/35°). The analytical results have also indicated that the existence of key blocks at the rock slope surfaces in the N - S direction, dip to E at the survey locations: HN-1, 13 and 14; and the slope surfaces in the NWW - SEE direction, dip to NEN at the survey locations: HN-4 and 11. These results have important significance to support for protecting slope surface safety.

4. Conclusions

The rock slope surface stability analyses are conducted based on the application of Hoek and Bray (2004) [4] and Block Theory of Goodman and Shi (1995) [3] from 834 fracture orientation measurements of the ten rock slope surfaces along the road, cut through the volcanic rocks of Hon Ngang formation, around the Hon Ngang island.

The analytical results have been determined, the average percentage of plane failure that can occur on the total rock slope surfaces is the largest, namely, the average percentage of plane failure is 18.41%, the wedge failure is 9.65% and the toppling failure is 9.98%. Because the road is excavated around the island, the direction of the rock slope surfaces is also changed accordingly. The analytical results of the rock slope surface stability in different directions of the road have also determined: the average value of fractures in the direction N - S, dip to W for plane failure is 17.48%, wedge failure is 10.85%, and toppling failure is 5.65%; the average value of fractures in the direction N - S, dip to E for plane failure is 22.69%, wedge failure is 13.01% and toppling failure is 10.78%; the average value of fractures in the direction NWW - SEE, dip to NEN for plane failure is 21.41%, wedge failure is 10.17% and toppling failure is 11.72%; the average value of fractures in the direction E - W, dip to S for plane failure is 12.76%, wedge failure is 5.13% and toppling failure is 10.91%.

Besides, the analytical results have also identified five rock slope surfaces that occur keyblocks: HN-01 (keyblock 129°/24°); HN-04 (keyblock 070°/33°); HN-11 (keyblock 035°/70°); HN-13 (keyblock 079°/36°); HN-14 (keyblock 122°/35°). These results have shown that the existence of keyblocks at the slope surface in the N - S direction, dip to E at the survey locations: HN-1, 13 and 14; and the slope surface in the NWW - SEE direction, dip to NEN at the survey locations: HN-4 and 11. These results have important significance to support for protecting slope surface safety.

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