

Prevention and remediation of rockslide at left portal of north tunnel of Da Nang – Quang Ngai expressway in Quang Nam, Vietnam

Phi Hong Thinh¹, Pham Quoc Tuan² and Pham Ngoc Minh³

¹University of Transport and Communications, Hanoi, Vietnam Vietnam

²Society of Rock Mechanics, Hanoi, Vietnam

³Transport Engineering Design Incorporation, Hanoi, Vietnam

E-mail: ¹phthinh.tomsk@gmail.com

Abstract. Da Nang - Quang Ngai Expressway is one part of the North - South Expressway of Vietnam being 130km in length, 24.5m in width. The Tunnel is a section of 4 construction packages with station of 22+500km – 23+000km. The tunnel is designed to go through a small hill, altitude of about 120m above sea level and 500m long and has two bounds – called North and South Tunnel. The North Tunnel has two portals – left and right. Bedrock is sedimentary rock (alternation of sandstone and conglomerate). Authors have investigated the field, detected inaccuracy in geotechnical investigation report, applied discontinuity model and failure criterion for anisotropic rock, analyzed stability of rock slope and proposed a solution to prevent rockslide at the Left Portal of the North Tunnel of the Expressway.

1. Introduction

Da Nang - Quang Ngai Expressway is one part of the North – South Expressway of Vietnam, being 130km in length, 24.5m in width. The tunnel is a section of 4 construction package with station of 22+500km – 23+000km. The tunnel is located at Duy Son and Duy Chung communes, Duy Xuyen district, Quang Nam province, Vietnam. The tunnel has two bounds - North and South. The North tunnel has two portals - Left and Right.

2. Geotechnical investigation and seismic survey

2.1 Geotechnical investigation results

The tunnel is designed to go through a small hill with altitude of about 120m above sea level and 500m long (Figure 1). Bedrock is a sedimentary rock (alternation of sandstone and conglomerate). Line of strike of the terrain is Northeast - Southwest with angle of about 60° from the North, bedding of bedrock dipping 30° to the Northwest.

- At Right Portal: many blocks of unstable rock located on the surface with different sizes (from 0.5 m to 5.0 m in diameter); plants grow poorly.

- At Left Portal: bedrock exposed on the surface at some positions, rock is highly weathered, plants grow well. However, surface failure (mass movement) is found near the tunnel: the new is about 15m in width x 30m in length on the South bound tunnel, the older is about 30m in width x 50m in length on the North bound tunnel.



- Geological condition of Left Portal: A layer of extremely weathered rock is found over the bedrock with different thickness of from 4 m to 0.65m. It is residual soil (sand with gravel, reddish brown, medium dense). Conglomerate and sandstone alternate below, the proportion of conglomerate and sandstone is 4:1. Particles of conglomerate is rounded and size of 2 to 20mm, fresh to lightly weathered condition. Permeability of the fracture zone is quite small (nearly 0.5mm/min with the pressure 1 kG/cm²), compression strength of lightly weathered rock is high, approximately 50MPa in average [2].



Figure 1. Location of Da Nang - Quang Ngai Expressway [7].

2.2 Results of seismic survey

Results of data seismic survey processing determined the velocity of the geological layers. At the same time, the positions of low longitudinal wave velocity zone were identified (in fracture and fault zones). The elastic parameters were determined according to each profile. The results of seismic survey in the North bound and South bound profiles showed many similar properties. The stratigraphic classification of the survey area is as follows [2]:

Layer 1: covering layer, rather thin, from 0 to 4.5m. Longitudinal wave velocities are between 400 to 1000m/sec. Modulus of elasticity is from 4 to 25 (1000 kG/cm²); modulus of deformation is from 0.25 to 2.5 (1000 kG/cm²).

Layer 2: average thickness is about 4m; at some positions in the profile of the North bound Tunnel there is a thickness of more than 6.5m. Longitudinal wave velocities are from 900 to 1800m/sec, almost above the groundwater level. Modulus of elasticity is from 20 to 81 (1000 kG/cm²). Modulus of deformation is from 1.8 to 10 (1000 kG/cm²).

Layer 3: average thickness is about 4m. Longitudinal wave velocities are from 2100 to 2300m/sec. Modulus of elasticity is from 122 to 133 (1000 kG/cm²). Modulus of deformation is from 10 to 15 (1000 kG/cm²).

Layer 4: thickness is from 7 to 9m in average, a few locations are thinner, about 5m. Longitudinal wave velocities are from 2700 to 3500m/sec. Modulus of elasticity is from 184 to 312 (1000 kG/cm²). Modulus of elasticity is from 25 to 60 (1000 kG/cm²).

Layer 5: longitudinal wave velocities in this layer are from 3700 to 6000m/sec, average value is 4200m/sec. Modulus of elasticity is from 349 to 932 (1000 kG/cm²). Modulus of deformation is from 75 to 400 (1000 kG/cm²).

Damage zones, faults and geological anomalies have been observed in six locations of each survey line. Longitudinal wave velocities are 2000 to 3200m/sec. Modulus of elasticity is from 100 to 260 (1000 kG/cm²). Modulus of deformation is from 10 to 40 (1000 kG/cm²).

3. On-site investigation results

According to on-site investigation results, the authors detected inaccuracy both in the geotechnical investigation report itself and studied and analyzed intact rock in this area. In situ intact rock has 2 fault systems with grade V. Intact sandstone location in Left Portal of the North Tunnel has 3 faults system and bedding system. The bedding system has direction angle of 15°- 20°; fault system perpendicular to bedding system has direction angle of 75° -80°; fault system that overlaps rock slope face has direction angle perpendicular to tunnel axis.

In addition, according to the results of topographical survey, intact rock in study area is tectonic system of grade II and is divided into river delta and hilly regions (Figure 2).



Figure 2. Geological structure around the Left Portal of the North Tunnel.

The investigation results showed that rockslide could have happened at the Left Portal of the North Tunnel during the construction or constructing or exploitation the Tunnel itself.

Authors applied discontinuity model and failure criterion for anisotropic rock, analyzed stability of rock slope and proposed a solution to prevent rockslide at the Left Portal of the North Tunnel of the Expressway. The software SLIDE by Rocscience (Canada) is used for stability calculation.

4. Profile and geological cross section for calculation

Base on documents of project and investigation results on the site, authors established profiles and geological cross sections for study area, as follows:

Table 1. Geological cross section.

No.	Name of section	Location	Remark
1	Profile of axis North Tunnel with study area Left Portal		
2	Cross section MC01	Km23+031	
3	Cross section MC02	Km23+041	Left Portal

Geological cross sections with dimension, arrangement and structure of the tunnel updated from drawings of construction contractor are shown in Figures 3 to 4.

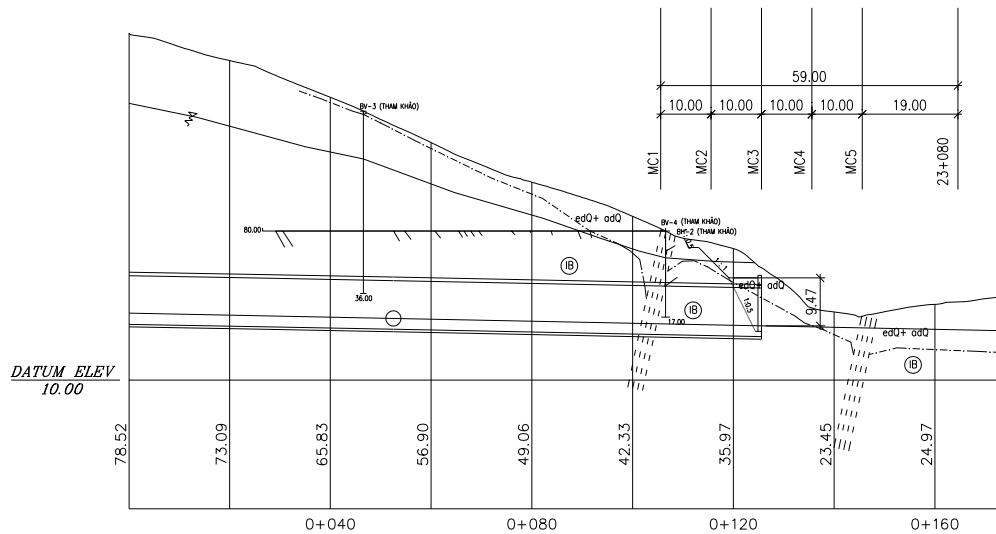


Figure 3. Profile of axis North Tunnel with study area Left Portal.

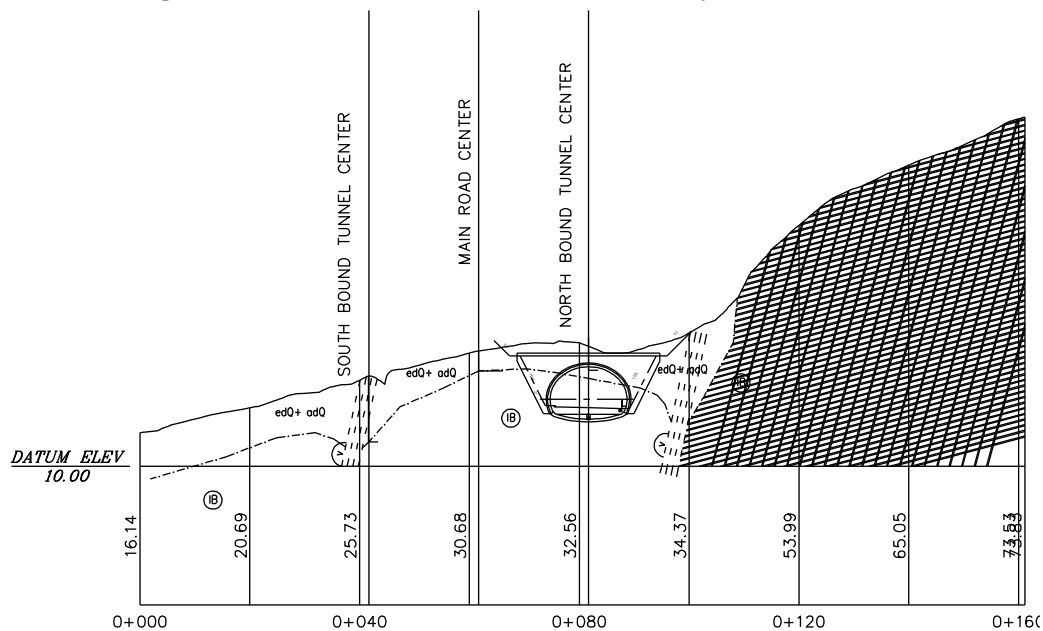


Figure 4. Geological cross section MC02

Geological cross section MC02 at location of the Left Portal is used for stability calculation.

5. Parameters of intact rock and soil to be used for stability analysis of rock slope

- Layer 1: completely weathered sandstone - green grey, brown, stiff sandy clay with thickness of 0.5 to 1.2m (Table 2).

Table 2. Parameters of the layer 1.

Case of analysis	Bulk density γ (kN/m ³)	Internal friction angle ϕ (degree)	Cohesion c (kPa)
Natural	17.0	19	20
Saturated	20.0	16	14

- Layer 2: Parameters of sandstone mass are determined according to Hoek - Brown methods with RocLab software of Rocscience, as seen in Table 3 and 4.

Table 3. Input parameters of the layer 2 for RocLab software.

Case of analysis	Unconfined compressive strength of intact rock σ_{ci} (MPa)	Geological strength index GSI	Intact rock parameter m_i	Disturbance factor D	Type application
Natural	50	65	17	0.8	Slope (15m)
Saturated	25	65	17	0.8	Slope (15m)

Table 4. Output rock mass parameters according to Mohr-Coulomb method determined by RocLab software.

Case of analysis	Bulk density γ (kN/m ³)	Internal friction angle ϕ (degree)	Cohesion c (kPa)
Natural	25.4	58.70	457
Saturated	25.4	55.08	276

- Bedding layer: physico-mechanical parameters of bedding layer are determined as parameters of hard clayey soil (Table 5).

Table 5. Physico-mechanical parameters of bedding layer.

Case of analysis	Bulk density γ (kN/m ³)	Internal friction angle ϕ (degree)	Cohesion c (kPa)
Natural	17.0	19	36
Saturated	20.0	16	21

Fault system perpendicular to bedding system: parameters of fault system perpendicular to bedding system are determined according to Hoek – Brown method. Its cohesion has been determined by 20% of cohesion of rock mass (according to Hoek – Brown method) (Table 6).

Table 6. Parameters mechanical and physics of fault system perpendicular with bedding system.

Case of analysis	Bulk density γ (kN/m ³)	Internal friction angle ϕ (degree)	Cohesion c (kPa)
Natural	17.0	33	91.4
Saturated	20.0	29	55.2

6. Cases of calculation

Case 1 (natural construction condition): parameters for calculation used in natural condition.

Case 2 (construction is conducted in raining condition): parameters for calculation used in saturated condition.

Case 3 (exploiting the tunnel in typhoon or flood condition): initial seep flow in layer rock and soil.

Case 4 Rock slope is supported by anchors with tensile capacity of 300kN, spacing of 2m; bond length equals 10% of anchor length.

7. Results of rockslide calculation

Summary of calculation results is shown in Table 7.

Table 7. Calculation results of factor of rock slope stability at geological cross section MC02.

Case of calculation	With circular slipping			With non circular slipping	
	Bishop simplified	Janbu simplified	Ordinary	Spencer	Janbu simplified
Case 1	2.052	2.094	2.388	-	6.628
Case 2	1.783	1.895	1.771	1.914	1.778
Case 3	-	-	-	1.138	1.046
Case 4	1.230	1.265	1.511	-	-

8. Conclusion and recommendation

Calculation results show that rock slope stability factor in all cases ensured the conditions of equilibrium limit. However, it should also satisfy the condition of limiting rock slope stability factor [FS]. According to Vietnamese standard, [FS] it is 1.2 for rock slope. So, the rock slope stability factor in case 3 does not satisfy Vietnamese standard. Rockslide may happen at the Left Portafactor 1 of the North Tunnel when constructing and exploiting the Tunnel in typhoon or flood conditions.

In Vietnam, anchor is being used to prevent landslides and rockslides at some projects such as Noi Bai – Lao Cai Expressway, Hai Van Tunnel and etc. The anchor method is a highly effective one and of reasonable price. Thus, we propose that anchors should be used to prevent rockslides at the Left Portal of the North Tunnel. Anchor bars have tensile strength of 300kN, spacing of 2m; bond length equals 10% of anchor length. Calculation results in case 4 show that the rock slope stability factor (FS) is greater than in [FS].

Acknowledgments

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