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Seismic resistive design for tunnel approach – A case study of Rohtang region

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ABSTRACT

Modernization demands enhanced infrastructural development in every corner of any nation. Integrated road network inhilly area itself is a big challenge. Construction of tunneling projects tend to increase the road networks connectivity in hilly terrain. This improves traffic capacity, which enables frequent mobility of transportsystems. A case study of vulnerable tunnel approach passing through tectonically active multi-folded rock mass of young mountains in Rohtang region has been discussed. Estimated 8.8 km long Rohtang tunnel (NATM tunneling) was proposed passing through diversified geological sequence of uniform dipping rocks having quartzite, quartzitic-schist and quartz-biotite schist with a thin band of phyllitescreating high stress flow due to overburden. Deep seated complex failure has been observed at this location. Tunnel squeezing and rock bursting occurred due to explosion, redistribution of elasto-plastic pressure during tunnelling works. The jointed rock is having NW-SE joint strike with 220/35° dip direction having three number of joint sets. In this case study, stability of around 200 m of affected scarp zonehas been addressed using FEM technique. Mohr-coulomb and Generalized Hoek- Brown parameters have been defined for overlying mass and underlying weathered, jointed bed rock strata respectively. Squeezing and exceeding of tangential stresses at the periphery of tunnel area as compared to unconfined strength of near lying disturbed rocks resulted in to high concentration of stresses at tunnel approach. Considering all these aspects, micropiles is used at intermediate levelsbelow road level with pre-stressed cable anchors at the tunnel passagelevel. Consequently, increase in strength reduction factor of 98 percentand 80.9 percent has been observed under static and seismic conditionrespectively. Control of massive displacement is major concern for this critical location. FEM analysis shows that stress displacement vectorshas been controlled up to 84 percent using stabilization techniques of cable anchors and micro-piles.

Keywords— *Cable anchor, Generalized Hoek Brown, micropile, Mohr-coulomb, multifolded, tunnel approach.*

1. INTRODUCTION

The presented case study incorporates the stabilization technique used for vulnerable tunnel approach passing through tectonically active multi-folded rock mass of youngmountains in Rohtang, INDIA region. Tunneling in multifolded jointed rock mass is crucial when it has to support rock masssliding adjacent to inlet of tunnel passage. Present case is the seismically active slide zone, where large displacement hasbeen observed. Geologically, the area is diversified withgeological sequence of uniform dipping rocks having quartzite,quartzitic-schist and quartz-biotite schist with a thin band ofphyllites creating high stress flow due to overburden mass.There are various slope protection arrangements which are rock bolts, construction in benches, remove overburden, toe protection schemes such as retaining wall, gabion structure etc.Sometimes situation arises when it becomes necessary to usecable anchors to hold the sliding mass and minimize the destabilization forces. Cable anchors are group of strands bonded together to form tendons which are then generally postensioned and act as active member [3]. Anchors are workablefor design load in gravel up to 80 ton using injection groutingand up to 500 ton in sand using compaction grouting.Prestressed cable anchors resist the failure of sliding mass along failure plane; thereby provides global stability. Inaddition, mircopiles are getting in to recent advancements whichhas lateral stiffness and performs well in seismic activity withminimal construction disturbance [1]. Present case describesthe feasibility of implemented post tensioned cable anchors forthe face protection at toe of slope near tunnel approach andintermediate micropiles (Type C) with casing using Rocscience Phase2 v8 finite element approach.

2. FINITE ELEMENT ANALYSIS OF CRITICAL SLOPE PROFILE

2.1 Geotechnical and Geotechnical Investigation

To start with FEM analysis; geotechnical investigations have been done taking borehole at south portal of tunnel up to depth of 30m. Bore holes chart shows the core recovery and analyzed RQD. Up to depth of 21 m pieces of boulders, cobbles and pebbles of phyllite was collected through bore log data. Jointed rock mass encountered at depth of 26.4m continued up to 31.5

m depth. A typical bore log sheet is attached shown in fig. 11 of appendix.

Triaxial tests have been conducted for collected samples from bore holes. In order to confirm the shear strength parameters collected form the testing; back analysis has been conducted using FEM program which defines the shear strengthparameters at the time of failure. Following figures provide representation of typical weathering profile [8] and characteristics of joints/discontinuities in rock mass [9]

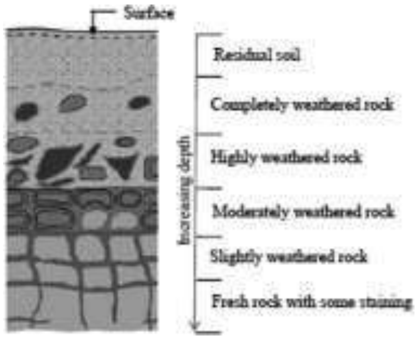

Fig. 1: Typical weathered rock slope profile

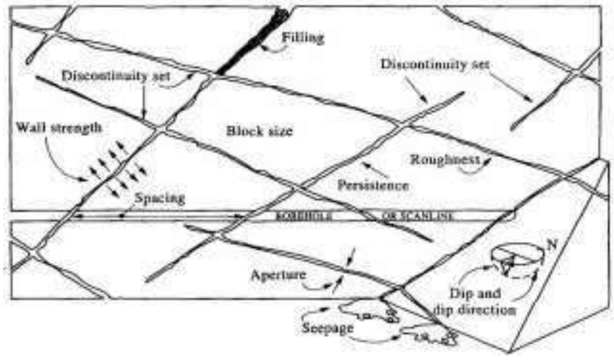

Fig. 2 Typical diagram showing discontinuities the rock mass

2.2 Geological Issues Pertaining at Site

Issues of mass movement can be seen from the site images as shown in figure. Vertical settlement has been observed at the road site near tunnel passage. Immediately below creep has been observed, which can be clearly seen form the tilted trees at the valley site. Piezometer has been installed at the site to record the pore pressure; this pressure tends to replace the cohesion of soil particles by water particles.

Fig. 3: Site observation made at critical location

2.3 Outputs of Geotechnical Investigation and Back analysis

Shear strength properties derived for undisturbed representative samples collected from boreholes using triaxial test and validated with roclab data software and also back analyzed. Generalized Hoek-brown constants [2,11] can bederived using equations 1-4 based and GSI value (42 for intermediate highly weathered phyllitic-quartzite layer and 62 for jointed bed rock) derived from Hoek brown chart.

$$m_b = m_i * \exp\left(\frac{GSI - 100}{28 - 14D}\right) \quad (1)$$

$$s = \exp\left(\frac{GSI - 100}{9 - 3D}\right) \quad (2)$$

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \quad (3)$$

$$E_{rm}(MPa) = E_i\left(0.02 + \frac{1 - D/2}{1 + e^{((60+15D-GSI)/11)}}\right) \quad (4)$$

Table I: Units for magnetic properties

Material Type	Over burden Strata	Weathered Phyllitic-Quartzite	Bed Rock Phyllitic-Quartzite
Material Model	Mohr-Coulomb	Hoek-Brown	Hoek-Brown
Unit Weight	19	26	29
Cohesion (kPa)	62	-	-
Friction Angle	31	-	-
mb (peak)	-	0.365	1.524
s(peak)	-	0.0000634	0.0017761
a(peak)	-	0.5099	0.5025

2.4 Methodology Adopted for FEM Analysis

Critical slope section is modelled in phase2 having slant length of slope approximately 200 m with average inclination angle 40 degree. Six-noded triangular element having uniform gradation has been adopted for the analysis with hinged supportcondition at the base and roller support in vertical direction. Input strength parameters has been adopted as discussed in table. Critical strength reduction factor has been analyzed for the slope without implementation of stability techniques. It has been observed that up to 145 m slope length deformationvectors creating slope destabilization.

In order to arrest these stress deformations, slope has been stabilized using post tensioned cable anchors (with seven strands) having ultimate design capacity (f_u x A_s) of 1200 kN having yield strength more than 1770 N/mm^2 and prestressing force is assumed to be 70 percent of ultimate design capacity i.e. 900 kN for 15.2mm five number of strands. Fixed anchor length calculated as per as per cl- 3.7, IS-14448 [16]. Safe bound strength for different rock mass based on RMR is considered from table 2, IS 14448 [16]. Structural design of RCC cladding wall is done as per IS 456: 2000 [12], from which thickness of wall 400 mm and size of base plate 350mm x 350 mm is derived for 25 ton/m^2 bearing capacity of supporting rock mass. Seismic coefficients in terms of horizontal (α_h) is calculated 0.15 and vertical seismic coefficient (α_v) as 0.1 acting along gravity direction and away (towards right) from the slope. [10]

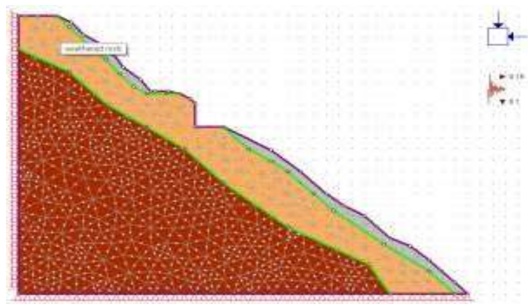

Fig. 4: Typical six-noded triangular elemental mesh for slope profile

Steel encased micropile (300 mm diameter) with 8 mm casing thickness is designed having lateral load capacity 2 ton calculated as per FHWA, 2005. Allowable tensile is 138 ton and compressive load of 190 ton derived from FHWA NHI-05-039-clause 5.6 [13, 14].

2.5 Output generated from FEM analysis

Analysis of generated model completes with output results in the form of critical strength reduction factor of slope without stabilization and then getting safety, controlled deformation and stresses using mitigation measures. From fig. 4 showing yielded elements it can be seen that there is predominant stresses and deep seated failure captured near tunnel passage. This may be due to high overburden, highly jointed crushed rock mass overlying the jointed bed rock.

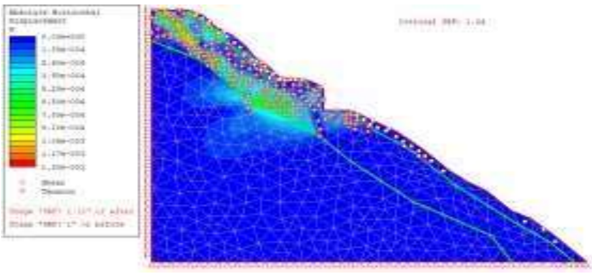

Fig. 5: Yielded elements of slope with critical SRF at static condition

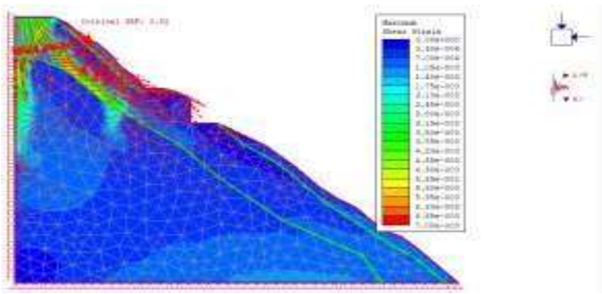

Fig. 6: Deformed stress trajectories at seismic condition (Zone IV)

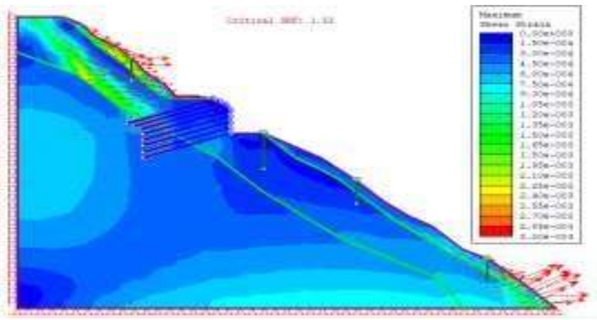

Fig. 7: Controlled stress trajectories and deformations using post tensioned cable anchors and intermediate micropile at static condition

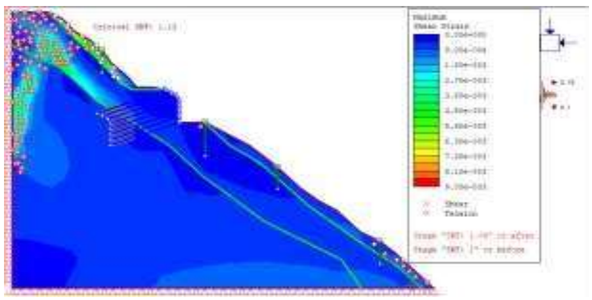

Fig. 8: Controlled yielded elements using post tensioned cable anchorsand intermediate micropiles at seismic condition (Zone IV)

Following figure 9 shows the stability charts under static and seismic conditions with corresponding absolute horizontal displacements. Increase in strength reduction factor of 98 percent and 80.9 percent has been observed under static and seismic condition respectively.

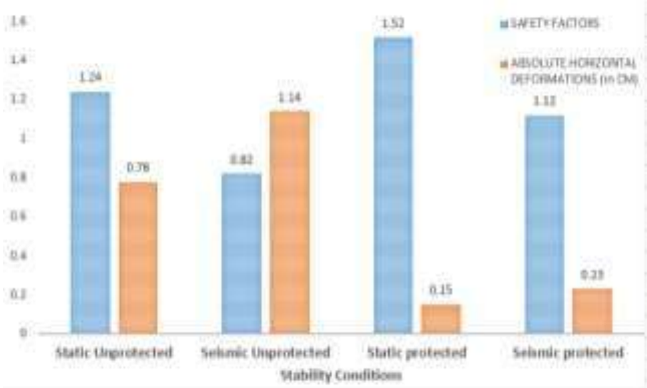

Fig. 9: Graph showing variable safety factors and displacements atstatic and seismic conditions

2.6 Implemented cable anchors at tunnel passage

Post tensioned cable anchors with 10m FAL (fixed anchor length) stressed up to 900kN having 2.5m vertical x 2 m horizontal spacing. Before installation of cable anchors pull out test has been conducted at the site as per IS 11309:1985. Following site images shows the implemented mitigation measures against the mass movement problem and stress concentration near tunnel passage.

Fig. 10: Installed post-tensioned cable anchors near tunnel passage

3. CONCLUSION

Analysis results concludes that post tensioned cable anchorage provides the global stability at the road level, wherelocalized stress concentrations are observed.

Post tensioned cable anchors act as passive member which resists the sliding through bearing stresses developed on reinforcement perpendicular to the relative movement. conclusion section is not required. In addition, encased micropile prove to be an effective mitigation measure providing stability against lateral movement due to its shear, tensile and lateral load capacity. Important points to be noticed that while starting the FEM analysis one should have confirmation of shear strength parameters which can be validated from back analysis using shear strength reduction technique. Pour water pressure also plays a crucial role creating destabilization of slope. Proper drainage networks should be installed in terms of weep holes in cladding walls, vertical drains and longitudinal catch drains by identifying the phreatic line.

REFERENCES

[1] A. Cadden, J. Gomez, D. Bruce and T. Armour, “Micropiles: Recent Advances and Future Trends,”

Current Practices and Future Trends in Deep Foundations, Los Angeles, United States, 2004, pp. 140-165.

[2] E. Hoek and E.T. Brown, "Practical estimates of rock mass strength," *International Journal of Rock Mechanics and Mining Sciences*; vol.34, no.8, pp.1165-86, 1997.

[3] BS 8539: 2012, "Code of practice for the selection and installation of post installed anchors in concrete and masonry".

[4] S. Gupta, "Design of prestressed cable anchor for stabilization of the Himalayan slopes," Dissertation, IIT Roorkee, 2006.

[5] IS 14268: 1995, "Uncoated stress relieved low relaxation seven-ply strand for prestressed concrete," by Bureau of Indian Standards (BIS), New Delhi.

[6] IS 10270: 1982, "Guidelines for design and construction of prestressed rock anchors," by Bureau of Indian Standards (BIS), New Delhi.

[7] G.S. Littlejohn, "Soil anchors" in Proceedings of ground engineering conference, Institution for Civil Engineer, London.

[8] H. Rhardjo, K.K. Aung, E.C. Leong and R.B. Rezaur, "Characteristics of residual soils in Singapore as formed by weathering," *Eng. Geol.* 73, 157–169, 2004.

[9] J.A. Hudson and J.P. Harrison, "Engineering Rock Mechanics," *An Introduction to the Principles*, Pergamon, Oxford, pp. 444, 1997.

[10] IS 1893 (Part-1):1997, "Criteria for Earthquake Resistant Design of Structures."

[11] IS 13365 (Part-1): 1998, "Quantitative Classification System of Rock Mass – Guidelines," PART 1: RMR for Predicting of Engineering Properties.

[12] IS 456: 2000, "Plain and Reinforced Concrete" – Code
of Practice.

[13] Federal Highway Administration (FHWA), "Micropile Design and Construction Guidelines: Implementation Manual," USDOT Publication No. FHWA-SA-97-070, 2005.

[14] Micropile Design and Construction, Reference Manual, Publication No. FHWA NHI-05-039, NHI Course No. 132078, 2005.

[15] G. Yang, Z. Zhong, Y. Zhang and X. Fu, "Optimal design of anchor cables for slope reinforcement based on stress and displacement fields," *Journal of Rock Mechanics and Geotechnical Engineering*, 2015, doi: 10.1016/j.jrmge.2015.04.004.

[16] IS 14448: 1997- "Code of Practice for Reinforcement of Rock Slopes with Plane Wedge Failure."

APPENDIX

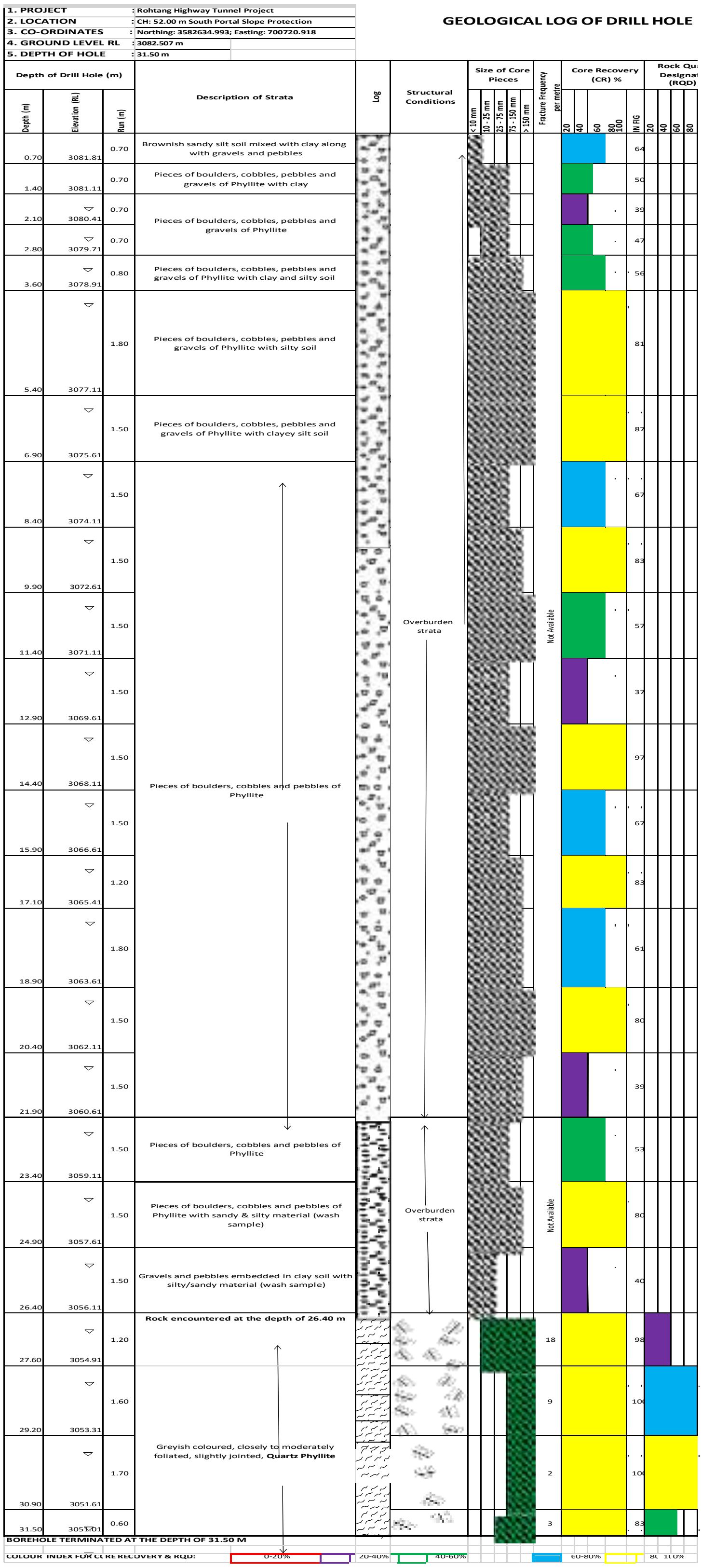

Fig. 11: Bore log data sheet showing RQD and core recovery collected for the sample

