Empirical Vs Dis-Continuum Analysis & Support Design of Bhatan Road Twin Tunnels (18m x 9.5m): A Case Study

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Abstract— In this paper, analysis and support design of the Bhatan tunnels have been carried out using empirical approach as well as numerical modeling approach. The cross section at particular intervals having a cover of 29m has been considered for the study. The rock mass classification and the support requirements have been determined using the widely used Q system of empirical approach. Stress analysis using Numerical methods being increasingly accepted for design of underground excavation due to their ability to consider most of the complexities and the reliability to produce realistic information. The two-dimensional discrete element modeling using UDEC version is used for stress analysis. The support system has been designed based on the deformations in the rock mass and slip and separation of the discontinuities around the excavation. The adequacy of the support system can be gauged from the reduction in the extent of rock mass failure and deformations. The comparison of the two methods have been summarized at the end.

Key words: Empirical, Dis-Continuum, Bhatan Road, Twin Tunnels

I. INTRODUCTION

Konkan Railway Corporation has taken up construction of twin road tunnels on Pune – Mumbai Express Highway. The tunnels consists of two parallel (18m x 9.5m) D - shaped tunnels at varying depth of over burden ranging from 10m to 135m with pillar width of 25m in basaltic rock formation.

II. GEOLOGICAL & ROCK MASS CLASSIFICATION

The Geological log in general indicates three prominent joint patterns which are as follows:

1) Horizontal Joints at roughly 2m spacing.
2) Sub vertical Joints with 80° dip at 0.2m spacing and
3) Sub vertical Joints with 100° dip at 0.4m spacing. The sub vertical joints pass through the crown.

III. EVALUATION OF ROCK SUPPORT SYSTEM BY EMPIRICAL APPROACH: (Q SYSTEM)

A. *Introduction*

Cross section (18m x 9.5m) D shaped tunnel with 29m cover and joint pattern has been considered for the analysis. It is a quantitative classification which facilitates the design of tunnel support. Q is the index of determination of tunneling quality of a rock mass. It is a function of three parameters such as

1) Block size
2) Interlocking shear strength and
3) The Active Stress

Q value is related to the tunnel support requirement by defining the equivalent dimension of the excavation. This method is suitable for highly jointed rock mass.

B. *Geo-Mechanical Parameters Considered From the Field Investigations*

SL NO	ITEM	DESCRIPTION VALUE	
1.	RQD	Fair	50
2.	Joint Set number Jn	3 sets plus random	12
3.	Joint Roughness number Jr	Rough and irregular, undulating	03
4.	Joint Alteration number Ja	Unaltered joint walls surface staining only	01
5.	Joint water reduction Jw	Dry excavation	01
6.	Stress reduction factor SRF	Medium stress	01

Table 1:

C. *Support Requirement from Charts*

Excavation support ratio (ESR) is related to the intended use of the excavation and to the degree of security which is demanded of the support system installed to maintain the stability of the excavation. Barton et al (1974) suggest ESR = 01 for power stations, major roads and railway tunnels, civil defense chambers and portal intersections.

From the charts shown in Figure 1,value of De (Equivalent dimension of excavation) of 18 and a Q value of 12.5, places this road tunnel in category 4 which requires a pattern of rock bolts spaced at 2.3m and 40 to 50mm un reinforced shotcrete.

IV. NUMERICAL MODELING APPROACH (DISCONTINUUM ANALYSIS)

The excavations of the tunnels causes redistribution of the Geo-static stresses and induces movements around them. The stress distribution and the deformation around them influence the design of the structure and the support requirements.

The Numerical modeling approach involving the discontinuum, requires the following

1) State of stress around the excavations.
2) Deformation pattern around the excavations.
3) Extent of failure zone.
4) Interaction of multiple excavation.
5) Design and verification of support system.

A. UNIVERSAL DISCRETE ELEMENT CODE (UDEC)

The distinct element method is recognized discontinuum modeling approach for simulating the behavior of jointed media subjected to quasi-static or dynamic condition. It is a two dimensional version of the method which is specifically designed to simulate the predominate features of fractured rock masses.

B. Computational Model for the Problem

Two dimensional plane strain model with discontinuities has been considered to study of behavior of the rock mass around twin tunnels, at a depth of 29m with joint patterns as mentioned earlier.

An typical geometry of the computational model with sufficient lateral extent to minimize the boundary effects. To identify a crucial joint pattern, cross section is developed at a particular chainage based on geological log. The insitu stresses and physico-mechanical properties of the rock mass, such as young's modulus, Poisson's ratio, Hoek and Brown parameters, Joint parameters, etc., have been incorporated in the analysis based on the field and the laboratory test results

Elasto–plastic stress analysis has been carried out simulating sequential excavation as done in the field. Stress analysis has been carried out without support system. To improve the stability of the excavations, support system consists of 150mm shotcrete and 4m long bolts at 1.5m to 2m spacing in the crown, to prevent joint separation and sliding as incorporated in a model. The effect of support system can be ascertained from the results of stress analysis in terms of reduced deformations, separations, sliding and stresses.

C. Simulation of Support Installation

Stress analysis has been carried out simulating following stages of excavation and support installation. The support system to be installed after rock mass under goes 50% of total deformation, without support system in the following sequence.

1) Complete excavation without support system.
2) After excavation of central (10m x 6m) core, before the installation of shotcrete and both.
3) After installation of support system and allowing complete deformations.
4) After complete excavation with support system.

D. Results & discussions

The displacement vectors, axial force in the bolt, axial force on the shotcrete, the factor of safety contours etc., for rock cover of 29 meter with four stages of support installation as mentioned above are shown in Table 2. Maximum roof displacement of 9.98mm is found near the joints. Maximum joint slip and separation are found along the joints near the roof of the tunnel. It is found that the factor of safety of the rock mass around the excavation is more than 2.0. The tensile stresses in the rock mass around the excavation are of the order of 0.42Mpa.

With the proposed support requirement of 150mm shotcrete and 25mm dia, 4m long bolts at 2m spacing in the crown, the effect of support system can be ascertained from the results of stress analysis in terms of reduced deformations, separations, sliding and stresses which are clear from the values given in the Table 1. Maximum deformation of 8.12mm is found in the roof. The reduction in the maximum displacement due to support system is of the order of 18%. The maximum joint separation and slip are reduced by 25% to 40% due to support systems. The shotcrete is subjected to maximum axial force of 297.6KN and the axial stress of 2Mpa. The maximum axial force in the bolt is 189.3KN.

E. Summary & Conclusions

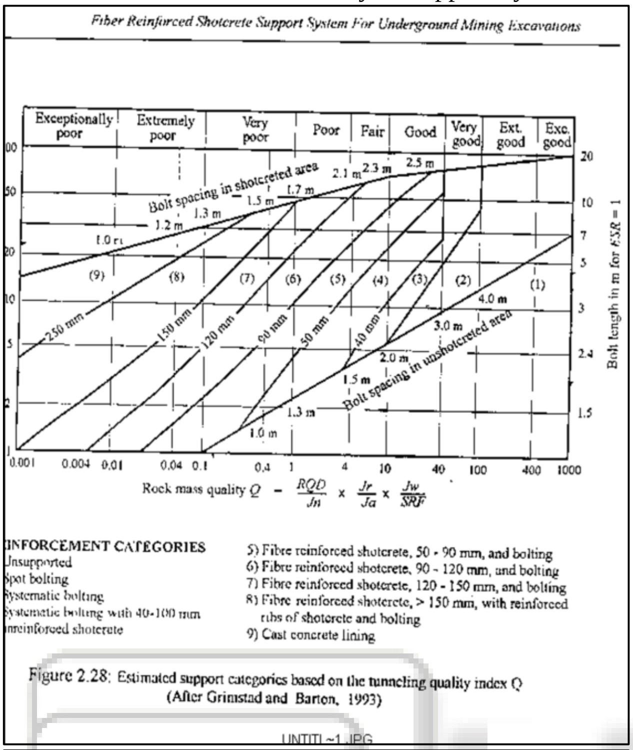
The support requirement for a cross- section at a depth of 29m cover, requires systematic bolting of 25mm dia with 3.2m bolt length and 40 to 100mm unreinforced shotcrete, whereas for the same cross-section by numerical method of analysis by assuming 150mm shotcrete and 25mm dia with 4m long bolts at 2m spacing in the crown are found to be adequate. The summary of the comparison of the two methods in general are as given below.

1) Q- system is based on the experience and the use of empirical formulae, whereas, the numerical methods are based on the real life situation and basically an approximation.
2) Using Q- system of method, support requirements such as rock bolt length and shotcrete thickness can be assessed using charts based on experience whereas in case of numerical methods, the datas such as displacements, stresses, bending moment, shear force, axial force, moment etc can be visualized.
3) The Q- system of method has less versatility compared to numerical method(UDEC).
4) Compared to Q- system the numerical method (UDEC) allows for analysis of sequential excavation.
5) Compared to Q- system it allows for analysis of variety of rock types and material laws to be used in the same analysis.
6) Errors can be rectified during the stimulation stage itself.
7) Various models can be designed for a given problem.
8) Compared to Q system it allows for analysis of different types of geometry and their combinations.
9) Back analysis can be done using Numerical Modeling.

Maximum values	29m cover			
	No Supports	Support Installation time	After installation	Final Installation
Displacement 1mm	9.98	3.88	6.05	8.12
Joint separation mm	5.57	1.55	2.41	3.43
Joint slip mm	4.40	2.40	4.36	3.28
Compressive stress Mpa	5.94	7.89	7.48	5.90
Tensile stress Mpa	0.40	0.42	0.40	0.41
Shear force on FRS KN	-	-	46.58	33.9

Moment on FRS KN-m	-	-	7.74	11.88
Axial force on FRS KN	-	-	492.1	297.6
Bolt load KN	-	-	191.0	189.0

Table 2: Summary of Support System Analysis (Numerical) For Bhatan Road Twin Tunnels



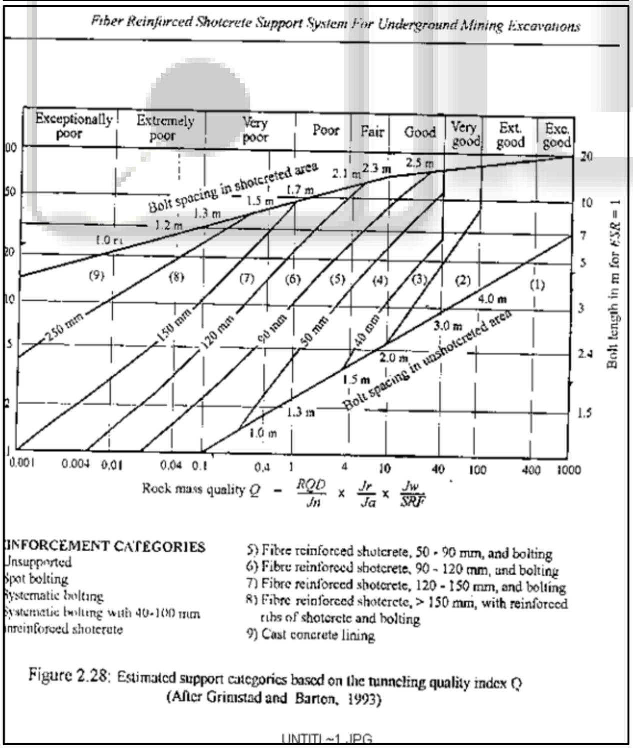


Fig. 1:

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