Tunnelling and Underground Space Technology 79 (2018) 224–230

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Prediction of rock mass rating using TSP method and statistical analysis in Semnan Rooziyeh spring conveyance tunnel

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ARTICLE INFO

Keywords:
TSP method
Statistical modelling
Water conveyance tunnel
Rock mass rate

ABSTRACT

In this study, the rock mass rating (RMR) value is assessed for a case-defined water transfer project, namely Rooziyeh spring. The progress paths of the tunnel and project quality are investigated using combined TSP and statistical modeling methods. The accuracy and validity of results are verified with respect to experimental RMR values obtained in the site plan. The developed models are investigated using the t- and F-statistical tests (with the confidence level of 99%), the determination coefficient and the estimation error. The investigation results showed that the developed models can reliably predict the RMR values based on the TSP test results of the Rooziyeh spring tunnel path. In addition, in order to validate the developed statistical models and to generate the prediction method to the other tunnel cases, the datasets of Koohrang water conveyance tunnel are provided as inputs. Therefore, the RMR and TSP results are studied in 11 zones of this tunnel with RMR values of 40–73. The average prediction error for linear and nonlinear models is 43% and 22%, respectively. Based on results, the nonlinear statistical models provide the highest accuracy than other linear models and thus are approved as accurate statistical models.

1. Introduction

A tunnel is an underground passage drilled artificially for uses such as water transfer or transportation. As tunnels must be used for long times and investment in such projects is very heavy, an accurate assessment, reduction in the time of drilling the tunnel, more confidence in investors, and reducing the risk in tunneling operation are essential. Several methods have been presented to obtain geological information of the tunnel path. Several researchers (Weng et al., 2015; Voit and Zimmermann, 2015; Okazaki et al., 2014; Qi et al., 2014) have studied the techniques that are able to determine the status around and in front of the tunnel excavation area quickly and accurately. Generally, the existing methods for predicting geological properties are divided into two groups, destructive and non-destructive methods, each of which has its own advantages and disadvantages (Wang and Huang, 2014). Destructive methods refer to those methods where destroying part of a wall or tunnel excavation to obtain intact rock samples and conduct experiments on them is inevitable in evaluation of tunnels. These methods have high accuracy as they have direct access to rock samples. However, they have a high cost and low speed. Non-destructive methods, which are mainly a part of geophysical methods, are applicable in both the surface and underground. These methods have been of great interest to engineers and employers of tunneling projects because of lack of destruction, high speed, and much less costs compared to destructive methods. Due to lack of access to rocky environment, non-destructive methods have higher errors than destructive methods.

There exist several valuable works considering prediction of geological properties. Ozcelik (2016) performed the rock mass classification of the tunnel grounds by utilizing the Rock Mass Rating (RMR), Q system and new Austrian tunneling method (NATM) which was followed by a geotechnical investigation along the tunnel. Shao et al. (2017) analyzed permeability measurements with nitrogen gas by performing the full-scale emplacement (FE) experiment and finite-element method (FEM) calculations with OpenGeoSys software with hydro-mechanical model. Kusui et al. (2016) determined a number of empirical relationships for the onset of spalling and pillar crushing for scaled-down tunnels drilled into three different material types. In addition, they obtained a distinctive ratio of compressive strength to induced stress for the different stages of progressive failure. Tokgöz et al. (2015) examined the excavation of fine-grained sedimentary soils by EPB TBM method in tunnel route. They evaluated the geotechnical and TBM excavation data by multiply linear regression method and provided a reliable numerical predicting advance rate, based on torque, plasticity index and clay content. Xiao et al. (2016) presented a study

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https://doi.org/10.1016/j.tust.2018.05.001
Received 1 July 2017; Received in revised form 16 April 2018; Accepted 2 May 2018
0886-7798/

Fig. 1. Geographical location of Rooziyeh Spring, Semnan.

Table 1
Various modes of recorded waves in study phases.

Mode	Index	Additional consideration in under study case
1	O_0	Data survey direction parallel with region general bedding orientation
2	O_1	Data survey direction in opposite direction of region general bedding orientation
3	W_1	Longitudinal wave record
4	W_2	Shear and horizontal wave record
5	W_3	Shear and vertical wave record

Table 2
Considered modes for statistical analyzing.

Mode	Index	Additional consideration in under study case
1	O_0	Data Survey Direction Parallel with region general bedding dip orientation
2	O_1	Data Survey Direction In opposite direction of region general bedding dip orientation
3	W_1	Longitudinal Wave Record
4	W_2	Shear and horizontal Wave Record
5	W_3	Shear and Vertical Wave Record
6	RMR_{+50}	Strong Region (High quality rock mass)
7	RMR_{-50}	Weak Region (Low quality rock mass)

Table 3
Considered combined modes for statistical analysis.

Mode	Index	Modes	Index
8	O_0 & W_1	14	W_1, O_0, RMR_{+50}
9	O_1 & W_1	15	W_1, O_1, RMR_{+50}
10	O_0 & W_2	16	W_2, O_0, RMR_{+50}
11	O_1 & W_2	17	W_2, O_1, RMR_{+50}
12	O_0 & W_3	18	W_3, O_0, RMR_{+50}
13	O_1 & W_3	19	W_3, O_1, RMR_{+50}

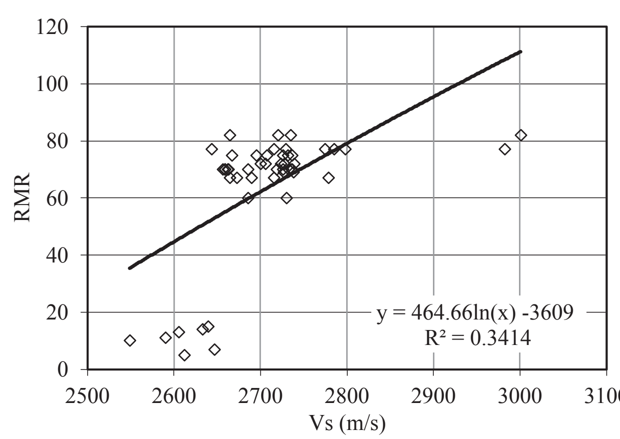

Fig. 2. RMR variation with V_s in Mode 2.

on the mechanical behavior in a long pipe roof during excavation of a shallow bias highway tunnel in loose deposits. They concluded that the force and bending moment distribution in the pipe roof was non-uniform during excavation as the stiffness of the retaining wall, protection arch, umbrella arch, and the surrounding loose deposits were different.

In advance, Gratzer et al. (2015) conducted comparative detailed geochemical analysis of retained reference samples, operational consumables and core samples from boreholes drilled into the tunnel wall and obtained the threshold values of hydrocarbons indices in the Reifling Limestone. Ritter et al. (2013) represented the individual steps