

Face Pressure Evaluation in Serviceability Limit State

Ebrahim Farrokh¹

¹Mining engineering faculty, Amirkabir university of technology (Tehran polytechnic)

ABSTRACT

In urban areas, tunneling is accompanied by ground surface settlement. In order to reduce the risks of operation, it is always required to have an assessment of ground surface settlement and face pressure. In the evaluation of the face pressure, there are two major sets of methods based on the ultimate limit state (ULS) (e.g. tunnel face failure), and serviceability limit state (SLS) (e.g. unacceptable settlement or heave). In a serviceability limit state, volume loss and surface settlement are used for the analysis of the face pressure. The methods developed for the analysis of SLS face pressure are based on the results of small scale centrifuge tests or case studies with unpressurized face. Hence, a realistic face pressure cannot be evaluated with these methods. This paper summarizes the major strategies for the evaluation of face pressure in an undrained condition. The outlined methods are utilized to evaluate tunnel face pressure in Tehran metro line 6, south extension (ML6-SE) project. Results of the analyses showed; predicted face pressures with the SLS methods are far above the required face pressure. In order to make realistic SLS face pressure evaluations in this project (considering a maximum allowable surface settlement of 10 mm), using ground characteristics and TBM operational parameters, a new formula is introduced with a coefficient of determination of 84%. The results of this paper can be very helpful for both the design phase of a tunneling project, and the construction period to adjust the face pressure based on the requirement of the allowable surface settlement.

KEYWORDS

Tunneling, face pressure, surface settlement, serviceability limit state, stability number.

1. Introduction

Urban area tunneling is tied to settlement control. In this regard, the main goal in tunneling practice is to keep these settlements within a safe level of damage (negligible or slight damage category with maximum ground surface settlement of 10 mm to prevent any uncontrolled damage to the surface structures and to fulfill the criteria set forward by the clients. In this regard, face pressure has to be defined with cautious to prevent any uncontrolled damage.

This paper presents a new empirical face pressure calculation method based on the principals of a service limit state to control the volume loss and ground surface settlement. For this, the results of a vigorous monitoring program to control maximum ground surface settlement in Tehran metro line 6, south extension (ML6-SE) project are analyzed and the correlation among major influential TBM operational parameters, maximum settlements, and stability number are discussed. On the basis of these results, a new formula is presented for the face pressure evaluation which can be used in similar tunneling conditions.

2. Methodology

In the evaluation of the face pressure, there are two major sets of methods based on the ultimate limit state (e.g. tunnel face failure), and serviceability limit state (e.g. unacceptable settlement or heave). These methods are well described by [1] and [2]. In clayey soils and in undrained conditions, stability number is the major factor used to evaluate the tunnel face pressure in both ultimate limit state and serviceability limit state.

In a serviceability limit state, a load factor which is the ratio of the stability number (N) and the critical stability number (Eq. 1) is usually used for the analysis of volume loss and face pressure (here face pressure is designed based on expected volume loss).

$$LF = N/N_{cr} \quad (1)$$

For Tehran metro line 6-south extension project, as the detailed information of the ground settlement was at hand; it was possible to set up a database to calculate the stability number based on the volume loss and some ground characteristics (with multiple linear regression using Minitab software) (Eq. 2). In this equation, stability number is a function of the face pressure. In order to fulfill the serviceability limit state, a certain volume loss or a certain ground surface settlement can be used in this equation to evaluate the stability number and the required face pressure. For this project, a limiting value of 10 mm is considered as the allowable

maximum ground surface settlement (S_{max}). With the use of S_{max} , it is possible to calculate the desired volume loss. When the limiting volume loss is defined, the stability number and subsequently the face pressure is calculated.

$$N = 0.0573 \frac{V_L^{0.2455} \cdot E^{1.118}}{(h_w/D)^{0.1531}} \quad (2)$$

where:

N = Stability number,

E = Young modulus (MPa),

V_L = Ground volume loss (%),

h_w = Tunnel centerline water head (m),

D = tunnel diameter (m).

3. Results and Discussion

Major findings from Eq. 2 are as follows:

- As the permissible volume loss increases, the stability number increases meaning the permissible stress removal is higher,
- In stiffer grounds with higher 'E' values, the permissible stress removal can be higher leading to a higher stability number,
- Tunnel sections with higher water heads require lower stress removal at the face, leading to a lower stability number.
- Fig. 1 shows a comparison between actual and predicted stability number along the tunnel using the new formula. As seen, there is a good agreement between the actual and predicted values.

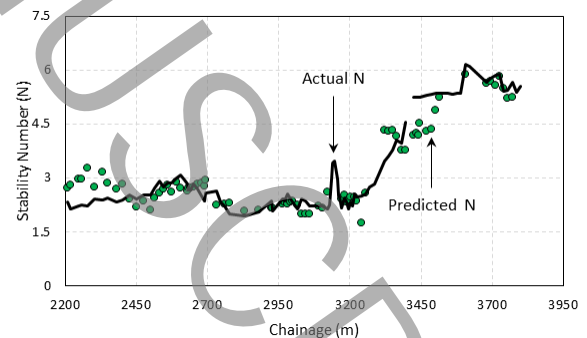


Figure 1. Comparison between actual and predicted stability number along the tunnel

4. Conclusions

In Tehran metro line 6-south extension (ML6-SE) project, extensive monitoring is conducted to control the ground surface settlement to ensure the TBM face pressure is well controlled, and the ground movement would not cause any excessive damage to the residential buildings within the proximity area of the tunnel drive. In this regard, a comprehensive data analysis is performed to identify the most influential parameters of the ground settlement and to provide face pressure prediction tool on the basis of statistical analyses and the principals of service limit state. The new formula introduced in this paper incorporates stability number, ground volume loss, water head, soil young modulus, and tunnel diameter. This formula can assist the operation during the phase of construction to adjust the face pressure on the basis of the observation and to limit the S_{max} below 10 mm, which is usually considered as

a safe level for the damage on the ground surface buildings. The analysis for surface settlement in ML6-SE for chainage 3200 to 3800 shows the face pressure (top sensor) is dropped to values close to zero. This increased S_{max} values above 20 mm. The proposed formula for the face pressure shows, in order to limit S_{max} below 10 mm in this area, it would be necessary to keep the top sensor pressure above 0.8 bar.

5. References

- [1] Zizka, Z., Thewes, M. 2016. *Recommendations for face support pressure calculations for shield tunnelling in soft ground*, German Tunnelling Committee, ITA-AITES.
- [2] Shirlaw, J.N., 2012. "Setting operating pressures for TBM tunneling". *Geotechnical Aspects of Tunnelling for Infrastructure Development*, Hong Kong, pp. 7-28.

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