Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(8) (2021) 791-794
DOI: 10.22060/ceej.2020.18036.6745

Face Pressure Evaluation in Serviceability Limit State

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ABSTRACT: In urban areas, tunneling is accompanied by ground surface settlement. To reduce the risks of the 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 the unpressurized face. Hence, 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 the Tehran metro line 6, south extension (ML6-SE) project. Results of the analyses showed that predicted face pressures with the SLS methods are far above the required face pressure. 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 was 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.

Review History:
Received: Mar. 05, 2020
Revised: Apr. 25, 2020
Accepted: May, 18,2020
Available Online: May, 28,2020

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 the 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 caution to prevent any uncontrolled damage.

This paper presents a new empirical face pressure calculation method based on the principles 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 the 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. Based on 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, 2]. In clayey soils and 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 the ML6-SE 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) as Eq. (2). In this equation, the stability number is a function of the face pressure. 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

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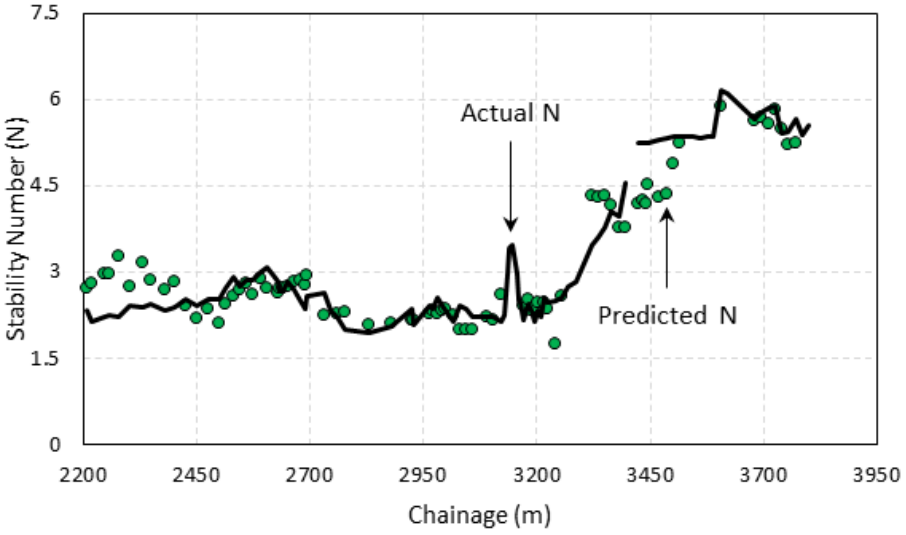

Fig. 1. Comparison between actual and predicted stability numbers along the tunnel

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 numbers along the tunnel using the new formula. As seen, there is a good agreement between the actual and predicted values.

4. CONCLUSION

In the 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 was performed to identify the most influential parameters of the ground settlement and to provide a face pressure prediction tool based on statistical analyses and the principles of service limit state. The new formula introduced in this paper incorporated 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 based on 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 the ML6-SE for chainage 3200 to 3800 showed that the face pressure (top sensor) was dropped to values close to zero. This increased S_{max} values above 20 mm. The proposed formula for the face pressure showed that 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.

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HOW TO CITE THIS ARTICLE

E. Farrokh, Face Pressure Evaluation in Serviceability Limit State, Amirkabir J. Civil Eng., 53(8) (2021) 791-794.

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