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Factors influencing the ground loss due to tunnels driven by EPB shield

C.T.Chang & J.J.Wang
Sinotech Engineering Consultants Limited, Taipei, Taiwan

Y.W.Chen
Department of Rapid Transit Systems, TCG, Taiwan

ABSTRACT: The ground loss and therefore the prediction of ground surface settlement during shield tunnelling in urban area is of utmost importance to ensure the safety of underground utilities or adjacent buildings. In this paper a generalized correlation between the surface settlement and some ground loss control measures is presented. Monitoring data on ground surface subsidence and field records of mucking, back-fill grouting and chamber pressure of the EPB shields acquired from the construction of Taipei's rapid transit tunnels were analyzed. It was found in this study that the major factors influencing the surface subsidence may include the quantity of grouttake, the volume of the tail void of the shield, the shield chamber pressure, and the depth of tunnel. A correlation between the ground loss ratio and the major factors were formulated through statistical models.

1 INTRODUCTION

The shield tunnelling method becomes more and more popular than the cut and cover method in well developed urban area due to its high flexibility in route selection, less impact to traffic, and simplicity in dealing with underground utilities. The innovation of the technology associated with the closed face shield machine reduced the risk of ground subsidence to the least extent through the active control of the face pressure and water tightness. With this safer construction methodology, the planners are endowed with flexibility in tunnel alignment, for instance, passing underneath existing structures. Therefore the engineers are facing with new challenges, i.e., how to predict ground subsidence more accurately.

Most researchers followed the model presented by Peck(1969) to predict the ground surface settlement, which assumed that the settlement trough will take the shape of a normal distribution curve. The accuracy of the prediction relies on the estimation of ground loss ratio which is defined as the area of settlement trough divided by the area of the advancing face of the tunnel. Clough & Schmidt (1981) proposed a chart based on field records and monitoring data which correlates the ground loss ratio with in-situ stress, pressure of compressed air, and undrained shear strength of the clay. It is considered by the authors that the chart is suitable only for cases where opened face machines with compressed air are used. A correlation for closed face machine, which relates the operating characteristics of the machine and the ground loss has to be set up.

2 DATA ACQUISITION

2.1 *Source of data*

The field monitoring data on ground subsidence as well as the records of the machine data from the shield tunnelling construction of the Taipei metropolitan area rapid transit systems forms the sources of this study. The data collected includes four subway lines in the Taipei basin with an extension of some 40 kilometers. The soils which the tunnel bored through are non-plastic silty sand with an N value below 10 and low plastic clay with an averaged plastic index of 15 and an average undrained shear strength of 50 kPa. The ground water is 1 to 2 meters below the ground surface level.

2.2 *Set up of a data bank*

A database was formulated via Excel® to handle the 4000 data points collected. Tremendous key-in work needs double check to avoid any misleading to the results.

The totally 4000 data points were divided into roughly 400 clusters. Each cluster represents a major monitoring section where data were recorded and comprised 11 data. They were serial number of the monitoring section, predominant type of soil at the tunnelling face, depth of tunnel, depth at which settlement data were taken, horizontal distance between tunnel center and the location where settlement data was taken, settlement amount, area of the advancing face of the tunnel, volume of disposal relating with each shoving of the shield, measured pressure at the earth chamber of the machine, volume of the grouttake for the filling of the tail void (the so-called back-fill grouting), and the pressure for the back-fill grouting. It has to be emphasized that the data concerning with the chamber pressure and the back-fill grouting were recorded at each advance of the shield throughout the tunnel but only the records at the location of the monitoring sections were utilized in this study. The chamber pressure was recorded once the cutting wheels passing underneath the monitoring section whereas the back-fill data were recorded once the tail of the shield passing underneath the same section. Therefore they won't happen at the same time but at the same place.

3 MODELING AND INTERPRETATION

3.1 *Shape of a settlement trough*

First of all, to have an accurate estimation of the subsidence needs a model which can generate a curve nicely fitting with the monitored settlement trough. The horizontal distance between tunnel center and the location where settlement data was taken and the settlement amount at that point were picked up from the databank and were fitted with the normal distribution curve by the least square method. It demonstrated a very nice fitting with a high value of R^2 (the coefficient of simple determination) . In general, the value is above 0.8 with the highest being 0.96 and the lowest being 0.37. This means that the shape of a settlement trough can be simulated by a normal distribution curve. The remaining tasks then become how to predict the volume of the trough and the location of the inflection point of the curve. The latter was beyond the discussion of this paper. Many discussions on it can be found in a former study by Wang & Chang (1995). The following of this paper will concentrate on discussion of the volume of ground loss.

3.2 *Correlation with the depth of tunnel*

By plotting the calculated ground loss ratio (refer to the definition at introduction) with the depth of tunnel at each monitoring section on Fig.1, one can find out that the data points are randomly scattered. The coefficient of correlation is as low as 0.285. The ground loss ratio varies from 0.45% to 3.26% with an average of 1.46% and a standard deviation of 0.57.

3.3 *Correlation with the volume of disposal*

The ground loss ratio and the volume of disposal are plotted together on Fig. 2. The coefficient of correlation is slightly higher, with a value of 0.44. The data points are scattered but with a tendency that the ground loss ratio becomes higher once the disposal is more than the volume of the shield. This is a rational trend which demonstrates how the excessive mucking will lead to ground subsidence.

3.4 *Correlation with the chamber pressure*

The ground loss ratio versus the earth chamber pressure divided by the depth of tunnel are shown on Fig. 3. The coefficient of correlation is -0.529. The negative value means the ground loss ratio decreases with the increasing of the ratio between chamber pressure and depth of tunnel. This phenomena can be interpreted as: For the same depth of tunnel, the higher the chamber pressure is, the less is the ground settlement.

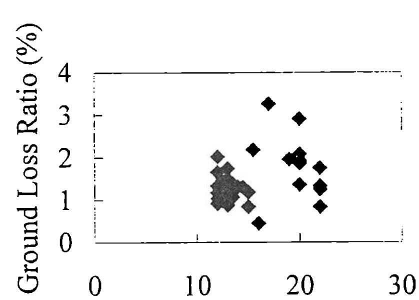

Figure 1. Correlation between the ground loss ratio and the depth of tunnel.

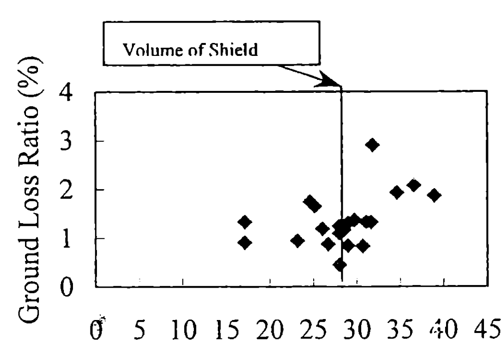

Figure 2. Correlation between the ground loss ratio and the volume of disposal.

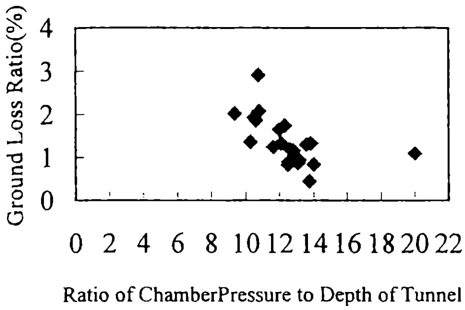

Figure 3. Correlation between the ground loss ratio and the chamber pressure divided by the depth of tunnel.

3.5 *Correlation with the volume of back-fill grouttake*

Fig. 4 shows the correlation between ground loss ratio and the volume of back-fill grouttake. The coefficient of correlation is –0.534 which is quite reasonable.

3.6 *Correlation with the pressure of back-fill grouting*

Fig. 5 shows the correlation between ground loss ratio and the pressure for back-fill grouting. The coefficient of correlation is –0.429. It is considered that some data which shows a constant pressure may be incorrectly recorded.

3.7 *The formulation of the prediction model*

It can be found from Fig. 1 through Fig. 5 that the chamber pressure and the volume of back-fill grouttake are factors which demonstrate best correlation with the ground loss ratio. This is obviously rational that field measurement on settlement reveal that most of the settlement occur at the face and tail of the shield.

If a non-dimensional factor GLI, Ground Loss Index, is defined as the sum of the division of back-fill volume by tail void volume and the division of chamber pressure by the in-situ stress at tunnel depth, the ground loss ratio can be predicted by the following formula:

Ground Loss Ratio (%) = $16.704*(GLI)^{-2.6017}$......(1)

Where

GLI=(grouttake/void)+
(chamber pressure/in-situ stress)...............(2)

The Ground loss ratio versus GLI are plotted on Figure.6. The coefficient of correlation is -0.663 which means that the normalized non-dimensional index, GLI, appears to be a better correlating factor than those individual factors as described above. Equation (1) fits quite well with the data points with a coefficient of simple determination of 0.4781. A linear regression is also plotted on Figure.6 with a coefficient of simple determination of 0.439. But a linear relationship is considered to be unreasonable because it yields the result that a GLI of 4 will lead to no settlement, which is almost impossible. Actually the shield will never be operated in such a way that a chamber pressure of twice the in-situ stress is maintained and the tail void is back-filled by grout to twice the volume of the inherent void.

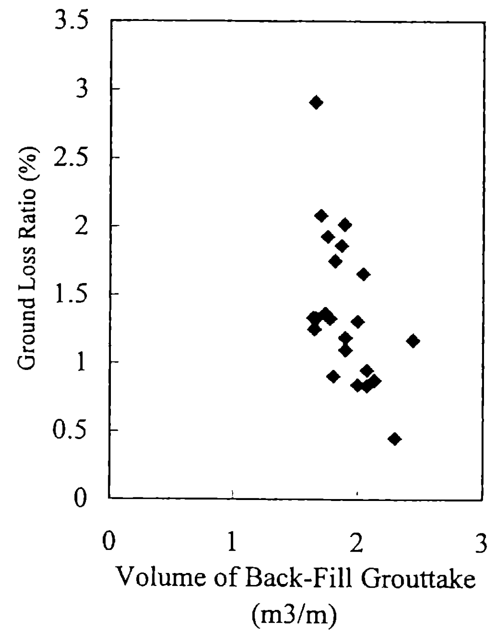

Figure 4. Correlation between the ground loss ratio and the volume of back-fill grouttake.

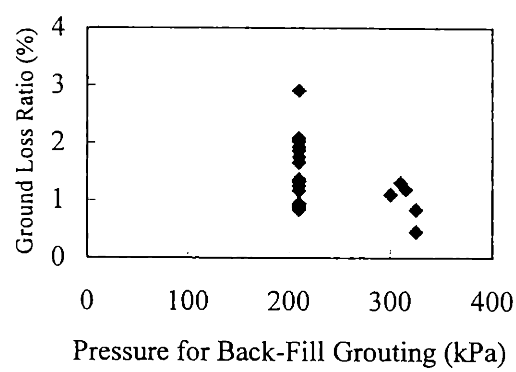

Figure 5. Correlation between the ground loss ratio and the pressure for back-fill grouting.

4 CONCLUSIONS

It can be concluded that the ground subsidence due to tunnelling by EPB shield can be estimated by the empirical formula presented above with the input of

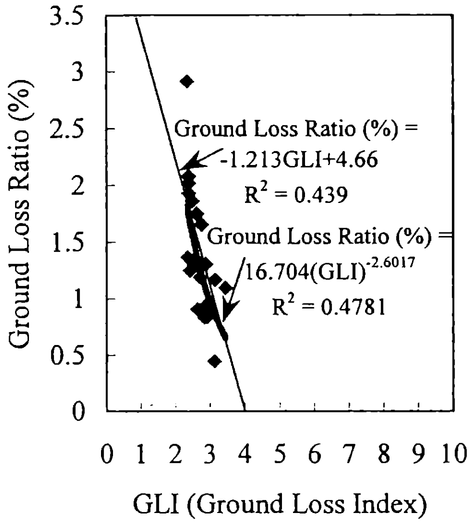

Fig. 6. Ground loss ratio versus ground loss index.

chamber pressure, in-situ stress, volume of grouttake, and volume of tail void. However, since the data were collected in Taipei basin, the study did not cover a wide range of soil conditions, therefore, the coefficients in the formula presented should be carefully adjusted if the formula is to be applied elsewhere.

From Fig. 6, it can be found that under good workmanship the GLI can be controlled within the range of 2.5 to 3.5 so as to limit the ground loss ratio to be under 2%.

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