GEOTECHNICAL EVALUATION AND ANALYSIS OF DELHI METRO TUNNELS

By

HOSH RAM YADAV

Department of Civil Engineering

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Dedicated

To

Mother, Father

&

E. Shreedharan

(M.D., DMRC)

CERTIFICATE

This is to certify that the thesis entitled, "**Geotechnical Evaluation and Analysis of Delhi Metro Tunnels**" being submitted by Mr. Hosh Ram Yadav to the Indian Institute of Technology, Delhi for the award of the degree of **DOCTOR OF PHILOSOPHY** is a record of the bonafide research work carried out by him. Mr. Yadav has worked under our guidance for the submission of this thesis which to our knowledge has reached the requisite standard.

The thesis or any part thereof has not been presented or submitted to any other University or Institute for any degree or diploma.

K S Rao
3.2.05

Prof. K. Seshagiri Rao
Professor
Department of Civil Engineering
Indian Institute of Technology Delhi

Prof. K.G. Sharma
Professor and Head
Department of Civil Engineering
Indian Institute of Technology Delhi

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3.2.05

Hosh Ram Yadav

(99RCE012)

ABSTRACT

The constantly increasing urbanization of the metropolises requires more and more realization of a fast and efficient transportation network. Underground transport lines often constitute an ideal solution in terms of efficiency and low nuisance for the environment. The technical advancements brought to the underground excavation methods allow the achievement of projects in difficult environmental conditions, especially in urban areas. But in spite of all precautions taken at the time of construction, face loss inevitably occurs around the excavation face and at the shield tail. These face losses propagate to the surface and provoke serious disruption to the existing structures and hence, resulting in serious consequences in terms of delays, cost and public image.

The Delhi Metro Rail Corporation (DMRC) is implementing its Phase-I presently. The Phase-I of Delhi Metro consists of 11 km underground corridor. The alignment of this corridor is passing through the major railway yards and highly buildup area in the walled city. Most of the structures in the area are quite old and constructed with spread footing and load bearing walls. The major modifications and additions in these structures have taken place due to commercialization of the area over the years. These modifications have been carried out without following any standard code of engineering practice. Therefore, the exact modeling of these structures is not possible due to absence of structural and foundation details. However, a detailed survey has been carried out by DMRC for the structures along the alignment in the influence zone of construction for the purpose of assessment of the health of these structures.

The geology in this built up area consists of quartzite and Delhi silt (alluvium). The rocks have undergone several tectonic activities in the area which has resulted in fracturing and folding. These disturbances and fluctuations of water table in the area have

resulted in intense and complex weathering pattern in the strata upto the depth of concern for construction of Delhi metro tunnels and satiations. Therefore, a comprehensive field study has been made for the rocks along the alignment for evaluation of rock masses. For physical, elastic and strength parameters, a comprehensive laboratory testing has been carried out for the rock masses of varying degree of weathering in IIT Delhi rock laboratory. The rock masses have been exposed to different degree of weathering and jointing. Detailed joint mapping (scan line survey) which included observations related to orientation, spacing, condition, infilling etc. was carried out in different traverses. Five field parameters, viz. (i) discolouration and staining (ii) texture and fabric (iii) disintegration (iv) decomposition and (v) relative strength, have been used to recognise different weathering grades as suggested by Rao and Gupta (2001). The six weathering grades (W_0, W_1, W_2, W_3, W_4 and W_5) suggested by ISRM (1981a) have been converged into three weathering grades viz. R_1, R_2 and R_3. These rock masses are slightly to moderately, moderately to highly and highly to completely weathered quartzite respectively.

On the basis of detailed field and laboratory studies, engineering properties of the rock masses have been evaluated and a generalized geological section along the alignment has been prepared. The major discontinuities observed are S_1, J_1, J_2 and J_3 at all locations of investigations. The alignment in the area is following almost strike direction of the main discontinuity (S_1). The engineering properties of alluvium overlain on the rock strata have been adopted from the Geotechnical Interpretative Report for the project (DMRC, 2002). The water table variations along the alignment with respect to the tunnelling activities have been considered on the basis of field observations taken from piezometers in respective areas by DMRC. The water table in the rocky strata was one to two meter below the ground level before start of construction in the area. But it has been observed that due to open mode working of the TBM and construction of Delhi Main and Chawri Bazar stations, the water table dropped almost at the invert level of the tunnels. The water table in the area where tunnelling had been done in the alluviums was maximum one to two meter above the crown level.

In view of above, the water table has been considered below the excavations for the analysis although the parametric study has been conducted for the variation of water table above the crown to address the influence of it on the analysis.

The problems for the analysis have been formulated in the Finite Difference code developed by ITASCA, USA by using Lagrangian algorithm. This code is termed as Fast Lagrangian Analysis of Continua (FLAC). The relevant concepts used in the code have been abstracted from the FLAC manual just for brief appreciation of the provisions of code being used in the analysis. Problems of deep tunnels with and without liner for elastic and elasto-plastic conditions have been formulated and analysed and the results have been compared with the relevant analytical closed form solutions. Simulation of face loss for the tunnels in alluvium has been carried out by providing equivalent gap between liners and excavated boundary and results have been compared with respect to the Peck's (1969) plots for settlement trough parameters.

The tunnels constructed in the rocky strata between Delhi Main and Chawri Bazar stations (B_2 area) by using Tunnel Boring Machine (TBM) have been analysed. The tunnels in this area are passing through quartzitic rocks of varying degree of weathering. The analysis has been carried out at primary reference lines (corresponding to lateral monitoring lines set up by the Delhi Metro Rail Corporation). Two additional sections in between the primary reference lines have been considered and are termed as secondary reference lines in the thesis. As this area is a highly built up area having non-engineered structures, therefore, the main concern was regarding effect of tunneling on the surface structures during tunneling. The analysis has been carried out considering greenfield condition as recommended by AFTES (1999) for prediction of settlement troughs on the ground surface. This assumption gives conservative prediction of settlement troughs at the ground surface.

The results indicate that the tunneling in this area does not show any appreciable concern for the surface structures due to negligible magnitude of settlement predicted from the analysis. The observed settlements are also very low. It has been noticed that due to increase in degree of weathering of rock mass the settlement at the surface does not increase appreciably. This is due to very low insitu stress conditions with respect to the strength of material and high modulus of the rock mass. To address the actual behaviour of the liner in the rocks due to the gap between the liners and excavated boundary which is invariably bound to be there due to the TBM, the four cases have been analysed viz.

Case I	:	Liner with gap (48 mm),
Case II	:	Liner without gap,
Case III	:	Without liner, and
Case IV	:	Liner only with self weight.

From the above cases it has been observed that the liner provided therein with the TBM is not being subjected to the ground loading immediately due to non-bridging the gap between liner and excavated boundary.

The analysis has also been carried out for the tunnels driven in Delhi silt (Alluvium) for the following three areas viz.

i. Kashmere Gate to Delhi Main (B_1)

ii. New Delhi to Connaught Place (B_4)

iii. Connaught Place to Patel Chowk (B_6)

The tunnels in B_1 area are passing through the busy Old Delhi Railway yard besides the area of high built up. The tunnels in B_4 area are passing through the New Delhi Railway yard and some other Railway establishments in Southern and Northern side of it. The tunnels in B_6 area are following the road (Parliament Street) in the major portion and passing adjacent to the historical monument Jantar Mantar. The tunnels in these areas have been taken for the study and the sections for analysis are corresponding to lateral monitoring lines in these areas and referred to as reference lines in the present work. The settlement troughs have been calculated for different face losses varying from 2 to 5 percent.

The results indicate that the face loss occurred during tunneling in alluvium is in between 2 to 4 percent in general other than at isolated locations. A detailed parametric study has been carried out for the tunnels in alluvium and the correlations have been established for the prediction of maximum ground surface settlement, maximum, axial force and bending moment in the liner incorporating the variables viz. face loss, cover above the crown, Young's modulus of the medium and water table above the crown level. These correlations have been validated with respect to the results obtained from the analysis for the tunnels in B_1, B_4 and B_6 areas. The predicted maximum ground surface settlements are comparable with the results obtained from the FLAC analysis.

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