STATIC AND DYNAMIC RESPONSE OF DELHI METRO TUNNELS

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by

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CERTIFICATE

This is to certify that the thesis entitled "STATIC AND DYNAMIC RESPONSE OF DELHI METRO TUNNELS", is being submitted by **Mr. SUBHASH SONI** in the partial fulfilment for the award of the degree of Doctor of Philosophy of the Indian Institute of Technology Delhi. This is a record of his work and is entirely carried out by him under our supervision and guidance. The matter presented in this report has not been submitted for the award of any other degree or diploma.

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"I believe in intuition and inspiration. Imagination is more important than knowledge. For knowledge is limited, whereas imagination embraces the entire world, stimulating progress, giving birth to evolution. It is, strictly speaking, a real factor in scientific research."

Albert Einstein, 1931

Doctor of Philosophy is not just another degree, but it marks the culmination of long years of academic education. I would like to take this opportunity to thank everyone who has contributed to my learning process since I was a child in school.

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"Attempt the end and never stand to doubt; Nothing's so hard, but search will find it out."

Robert Herrick, 1963

Subhash Soni

ABSTRACT

The ever increasing population of large cities, density of transportation and the need for storage capacity have led, inevitably, to an increased use of underground facilities. Many of these underground facilities often pass through soft ground (soil), complex geological conditions, and many of the projects are situated in active zones of high seismicity. It is necessary to understand the influence of the geological conditions, and stability of such soft grounds, including seismic activity and the resulting states of the stresses due to excavation and insitu stress condition on the engineering behaviour of the underground openings. Tunnelling using Tunnel Boring machine (TBM) is one of the most reliable and stable methods amongst the other available urban tunnelling techniques.

TBM tunnelling in an urban environment requires accurate prediction of ground movements around the TBM in order to assess any potential effect on the existing infrastructure. The empirical method and the finite element/difference methods are two common methods of predicting ground surface settlements induced by excavation. Unfortunately, most or all of the empirical methods adopt the zero plastic deformation approach and predict the surface settlement profile by adopting the normal (or Gaussian) distribution function or informally the bell shaped curve.

Most of the modern finite element/difference method (FEM/FDM) modelling techniques prescribe the deformation pattern around the tunnel excavation caused by the Tunnel Boring Machine (TBM) known as gap modelling. Standard uniform and oval-shaped volume loss models have been developed earlier by various authors and are used extensively to simulate TBM tunnel excavation in FEM/FDM modelling.

A Rational Modelling Technique (RMT) using FLAC 2D for the analysis of ground movement around TBM excavation is described. The proposed RMT is a

more realistic approach to simulate tunnel movements associated with TBM excavation as an alternative to prescribing the deformation boundary condition around the tunnel. The technique present is based closely on the rationalisation of TBM characteristics and tunnelling aspects and thus called as rational modelling technique (RMT) within the present thesis. The technique proposed herein can be briefly explained as a boundary condition applied by the TBM on tunnel excavation boundary with respect to time and/or forward motion of TBM. Tunnel stability is maintained using new programming code written within the FLAC 2D framework (Fish Function), based on the characteristics, functional aspects and different phases of the TBM excavation.

The proposed modelling (RMT) technique allows the tunnel to deform naturally and gradually during excavation as the TBM passes through the section. The RMT allows the tunnel to deform slowly so that the unbalanced forces are distributed throughout the model in order to provide a more accurate representation of the modelled volume loss.

The proposed modelling (RMT) technique could also be used to simulate multiple tunnel openings in close proximity and to simulate the interaction between multiple structures/tunnels.

In the present thesis, scope of work is limited to the assessment of ground loading and its impact on the tunnel lining.

In order to establish the proposed rational modelling technique, a case study based on actual TBM tunnel (twin tunnel, each 6.53 m diameter at Cutter-head) excavation completed along the selected reference line of the Delhi Metro Rail Corporation (DMRC) project is presented. The analysis has been carried out for the tunnels driven in Delhi silt for the between Connaught Place to Patel Chowk (Line-B6) on the Yellow line constructed in Phase I work of DMRC. Sensitivity analysis has been carried out and results are compared with the empirical method as suggested by Peck (1969), Attewell (1977), O'Reilly and New (1982), Yadav (2005) and field monitoring observations.

Delhi Metro tunnels are aligned under varying tunnel depths (10.5 m to 14.2 m) and varying centre pillar widths (7.2 m to 11.2 m). No well-established design chart or empirical correlation is available to predict the surface settlement in Delhi silt due to TBM tunnelling in these varying tunnel configurations.

A comprehensive parametric study was carried out for various models developed with combination of tunnel depths and separation or pillar width (called as clearance) ranging 1.5, 2.0, 2.5 and 3.0 times of tunnel diameter. Three volume loss cases (1.0%, 2.0% and 3.0%) have been adopted for estimating the surface settlement and tunnel lining response (axial force and bending moment) under various tunnel configurations. Following the extensive parametric study, empirical correlations have been developed for surface settlement, maximum axial force, and maximum bending moment. The results of the present study can be used for future design of relevant tunnel sections in the different field configurations in Delhi Silt.

Due to lack of actual earthquake data recorded in Delhi region, equivalent sinusoidal wave motion has been adopted for combination of expected peak ground accelerations and predominant periods for carrying out seismic analysis. A comprehensive parametric study was carried out for various models developed with combination of tunnel depths and clearance ranging 1.5, 2.0, 2.5 and 3.0 times of tunnel diameter.

Empirical correlation equations have been developed for calculating maximum surface settlement, maximum axial force and maximum bending moment in the tunnel liner under various seismic scenarios.

The presented thesis provides an easy to use empirical formulation for predicting surface settlement and liner response under static and dynamic conditions for the design.

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