EFFECTS OF EXCAVATION SEQUENCE AND HEADING DISTANCE ON SETTLEMENT IN NEW AUSTRIAN TUNNELING METHOD

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Effects of Excavation Sequence and Heading Distance on Settlement in New Austrian Tunneling Method

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A dissertation submitted in partial fulfilment of the

requirements for the award of the degree of

Master of Engineering (Civil-Geotechnics)

Faculty of Civil Engineering

Universiti Teknologi Malaysia

OCTOBER 2012

Dedicated with much love and affection to my beloved mother and father,
and all my family who always supported me

ACKNOWLEDGEMENTS

In preparing this dissertation, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my dissertation supervisor, Professor Dr. Aminaton bt. Marto, for encouragement, guidance, critics and friendship. Without her continued support and interest, this dissertation would not have been the same as presented here. I would like to thanks the Universiti Teknologi Malaysia (UTM) for providing facilities in the Faculty of Civil Engineering (FKA) during my study. The help from Tunnel Rod Company in providing data for the case study is highly appreciated. Thanks are also due to all technicians of Computer Laboratory, FKA, UTM for their assistance in the use of computer facilities.

My fellow postgraduate students should also be recognized for their supports in particular Mr. Mohsen Hajihassani and Mr. Eshagh Namazi. My sincere appreciation also extends to all colleagues and researchers in the Soft Soil Engineering Research Group, and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space.

Last but not least, I would like to acknowledge the emotional and financial supports given by my family members. Their continued support and encouragement enlighten my day and give motivation to complete my study in due time.

ABSTRACT

The shallow underground excavation may leads to ground movements and surface settlement which may cause damage to structures. Several tunnel excavation methods had been developed during the last decades to minimize the effects of the tunnel construction on the surface settlement. The Karaj Metro tunnel (KMT) had been constructed in accordance with the principles of the New Austrian Tunneling Method (NATM). This method had been used widely to construct large diameter tunnels mainly due to its flexibility to adapt different ground conditions. Tunnel designs by NATM are generally based on empirical and numerical methods and construction process may be changed according to the observed response of the ground. Induced displacements are empirically controlled by adjusting the excavation rate, distance between tunnel face and support, partial heading excavation and closure of invert. This research is aimed at determining the effects of the excavation sequence and heading distance on the surface and subsurface settlement by carrying out two and three-dimensional Finite Element Modelling (FEM). Initially, the FEM is carried out to simulate step by step excavation sequence of KMT which had been constructed in soft soils by NATM method. The settlements obtained from monitoring of KMT had been used to validate the modelling work. The results show that the settlement varies with different excavation sequence and heading distance in NATM. The Side Galleries (SG) excavation model produced the lowest transverse and longitudinal surface settlements compared to KMT excavation model and other excavation sequences. The tunnel heading distance had more effect on both the transverse and longitudinal settlements for the KMT excavation model compared to SG model. Hence, the SG excavation model with heading distance of 2 m is recommended in the construction of KMT using NATM based on the minimum settlement occurring during excavation.

ABSTRAK

Kerja-kerja pengorekan cetek bawah tanah boleh menyebabkan pergerakan tanah dan enapan permukaan, dan seterusnya boleh mengakibatkan kerosakan kepada struktur. Beberapa kaedah pengorekan terowong telah dihasilkan sepanjang beberapa dekad yang lalu untuk mengurangkan kesan kerja pembinaan terowong terhadap enapan permukaan tanah. Terowong "Karaj Metro" (KMT) telah dibina menurut prinsip "New Austrian Tunneling Method" (NATM). Kaedah pembinaan ini telah digunakan dengan meluas untuk membina terowong bergarispusat besar kerana kaedah ini sesuai digunakan untuk pelbagai keadaan tanah. Rekabentuk terowong yang dihasilkan menggunakan kaedah NATM adalah berdasarkan kepada kaedah-kaedah empirikal dan berangka, manakala proses pembinaan boleh diselaraskan menurut perubahan dan pergerakan tanah yang dipantau secara berterusan. Enapan yang teraruh oleh kerja pengorekan boleh dikawal secara empirikal dengan menyelaraskan kadar pengorekan, jarak antara permukaan terowong dan penyokongan, pengorekan separa permukaan terowong, serta pengecutan bumbung terowong. Penyelidikan ini bertujuan untuk menentukan kesan urutan pengorekan serta kesan jarak permukaan terowong terhadap enapan di permukaan dan sub-permukaan tanah dengan menghasilkan model unsur terhingga “Finite Element Modelling” (FEM) dalam dua dimensi dan tiga dimensi. Pada mulanya FEM diguna untuk mensimulasi urutan proses pengorekan secara langkah demi langkah bagi projek KMT yang telah dibina di dalam tanah lembut dengan kaedah NATM. Bacaan enapan tanah yang diperolehi daripada pengawasan proses pembinaan Terowong "Karaj Metro" telah digunakan untuk mengesahkan kerja-kerja pemodelan yang telah dilakukan. Keputusan yang diperoleh daripada kerja pemodelan tersebut menunjukkan bahawa nilai enapan tanah berubah dengan perubahan kepada urutan proses pengorekan dan jarak maju terowong di dalam kaedah NATM. Model pengorekan “Side Galleries” (SG) menghasilkan enapan-enapan melintang dan memanjang yang terendah dibandingkan dengan model pengorekan KMT dan urutan pengorekan yang lain. Jarak maju terowong memberi kesan yang lebih besar keatas enapan-enapan melintang dan memanjang bagi model pengorekan KMT dibandingkan dengan model SG. Justeru, model pengorekan SG dengan jarak pengorekan 2 m disyorkan untuk pembinaan KMT dengan menggunakan kaedah NATM berdasarkan kepada nilai enapan minimum yang berlaku semasa pengorekan.

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LIST OF SYMBOLS

γ	-	Unit weight
E	-	Young’s modulus
ν	-	Poisson’s ratio
ϕ	-	Internal friction angle
c	-	Cohesion
k	-	Permeability
K_0	-	Coefficient of lateral earth pressure at rest
N	-	Standard Penetration Test (SPT) Value
A	-	Excavation area
Z	-	Center point of excavation depth
V_L	-	Percentage of volume loss
L_{inf}	-	Location of inflection point
S_v	-	Vertical settlement on X-direction
V_s	-	Volume of the curve area
σ_Z	-	Soil stress at the centre of excavation
K_r	-	Coefficient of earth pressure at rest of cohesive soil
$S_{(y,z)}$	-	Vertical displacement

$H_{(y,z)}$	-	Horizontal displacement
i	-	Influence point
β	-	Reduction factor
P_r	-	Ground pressure due to stress reduction
P_0	-	Initial ground pressure
r	-	Tunnel radius

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Underground construction has become an important factor to reduce the congestion at the ground surface due to swift growth at the major cities. Tunnels are an important part of underground construction and the demand for tunnel transportation and safety excavation had been significantly increased for the development of rail or road tunnel systems in recent years. Hence, tunnels are increasingly used in the urban areas due to the growth of population.

Since tunnels have been constructed over hundred years, the design has improved gradually based on analytical solutions by engineers and with the advents of computer technology. In several cases, different numerical modelling such as domain or differential approach and boundary or integral approach has been used by the computer technology to simulate the tunnel construction. Excavation of a tunnel has some effects on distribution of insitu stresses in the tunnel neighbourhood, and it is formed as a new stress distribution around the tunnel. The construction of a tunnel through urban areas can lead to ground deformations whereby in several cases damage occurred to the overlaying structures and services.

The New Austrian Tunneling Method (NATM) was developed by Rabcewicz (1964) and Muller (1978) in Austria. The usage of NATM was undertaken in shallow and large tunneling into the rock mass; nowadays, the demand of NATM is for the use into the soil mass with different resistance. The method had been established based on the use of surrounding mass strength to stabilize the tunnel with a noncircular and enlargement of tunnel opening. The use of NATM tunneling method had been known to have cost saving and control the settlement. Using this method, after excavation the soft soil area of the cross-section at the tunnel face, shotcrete as a supporting system is applied on the tunnel walls, constituting a thin and flexible shell.

Several researchers had investigated the effects of heading distance on the NATM tunneling operation. However, limited research had been conducted to analyze the effects of different partial face excavation, in particular the sequence of the excavation, on the surface and subsurface settlement. Therefore, this study had been conducted to define the effect of ground movement due to NATM tunneling work. Hence, a specific excavation model needs to be provided to control surface settlements and minimize the potential impact on the surface structures. Thus, transverse, subsurface and longitudinal settlements need to be assessed from several excavation sequence method that can be conducted using a suitable excavation model.

1.2 Problem Statement

NATM is used in the large sized tunnels; so, full face excavation in the soils may cause large movements around the excavation area and subsequently at the ground surface. To reduce the stress distribution and yield zone around the tunnel, NATM tunneling offered the cross-section which is divided into several suitable parts in area and shape, in order to allow efficient and practical construction. The cross-section is excavated in each stage of excavation sequence. One of the important features in NATM tunneling is excavation sequences design, which depends on soil condition, tunnel geometry and tunneling requirements which may reduce the yield zone, consequently to minimize the displacement. On the other hand, heading distance may cause the main settlement with respect to various cross-sections.

Karaj Metro Tunnel had been constructed in urban areas with NATM method. The minimum settlement is important to avoid structures damage in the cities. In order to determined the optimum excavation sequence, several cross-sections with different multiface excavation with specific heading distance had been introduced for the Karaj Metro Tunnel. The one that gives the least surface settlement is recommended as the excavation model.

1.3 Aim and Objectives of the Study

The aim of this study is to determine an “excavation model” in NATM Tunneling that cause minimum surface and subsurface settlements using finite element method. The Karaj Metro Tunnel, Iran had been taken as the case study. Hence, the objectives of this research are:

1. To obtain the optimum excavation sequence by analyzing the ground response due to NATM tunneling using two dimensional finite element simulations for various excavation sequences, based on minimum surface settlement.

2. To predict the transverse and longitudinal surface settlements at different face-distance for the recommended excavation model and to compare with the results from existing Karaj Metro Tunnel excavation method, using three dimensional finite element simulations.

3. To determine the effect of different heading distance on the transverse and longitudinal settlements for both the Karaj Metro Tunnel and the recommended excavation models.

1.4 Significance of the Study

Based on this study the optimum excavation sequence and heading distance in NATM had been recommended. This could minimize the ground displacement and consequently building damages for the tunneling work through the same soil condition at the Karaj Metro Tunnel, Iran. Results could be used by tunneling engineers to plan the tunneling work of large diameters tunnel through soil, to obtain optimum performance.

1.5 Scope and Limitation of the Study

The research is limited to the immediate settlement occurred during construction using NATM operation through alluvial deposits that contains mainly of sand with appreciable amount of silt (SM-SC) at Line 2 of the Karaj Metro Tunnel, Iran. The long term time dependent consolidation settlement is not covered in this research.

In order to verify and evaluate the accuracy of the finite element (FE) models by the use of Plaxis and Abaqus software, the results had been compared with field measurement during the construction of Karaj Metro Tunnel project in Iran.

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