Journal of Civil Engineering and Environmental Technology
Print ISSN: 2349-8404; Online ISSN: 2349-879X; Volume 1, Number 4; August, 2014 pp. 45 – 48

http://www.krishisanskriti.org/jceet.html

Prediction of Ground Subsidence Due To Shallow Tunnelling In Soft Soil By Using Finite Element Analysis

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Abstract **:Construction of metro underground transportation network forms part of the basic infrastructure development which becomes essential in large metropolitan cities for dealing with the growing problem of mass rapid transit. Metro underground tunnels are built usually with a low overburden and close to the surface and beneath populated areas, thereby aggrandizing the consequences of failure. Going for much deeper tunnels in high populated cities will not be a wise decision as it will cause inconvenience to the public. Litigations related to structural damage caused by the ground subsidence and the claims for a just compensation have become acommon problem associated with such metro underground projects. Assessment of the influence of tunneling on the above ground structures has therefore become a very important and crucial issue in metro cities.**

Excavation of shallow bored tunnels invariably induces some amount of ground movement which is reflected at the ground surface in the form of a settlement trough. Settlement trough can occur in longitudinal direction (i.e. along the length of the tunnel) and in transverse direction (across the tunnel).

In this present study ground subsidence analysis has been carried out by conventional Deconfinementmodeling method, an attempt has been made to conduct a full 3-D elasto-plastic analysis with step-by-step simulation of excavation and sequence of construction.

(Keywords: Shallow tunnelling, Ground Subsidence,deconfinement modelling, settlement trough)

1. INTRODUCTION

Construction of shallow tunnel for metro rail will definitely induce some amount of surface subsidence. Important structures standing within the ground subsidence zone are likely to suffer damage and as such this needs to be studied thoroughly. In soft silty clay, study on ground subsidence due to shallow tunneling and its effect on surface structure is thought to be very important. A sincere effort will be made to investigate this problem in this research work.

The increased demand of public transportation in metropolitan areas and the scarcity of horizontal space led to an increased requirement for underground transportation.

We may encounter various types of structures in the alignment of the tunnel such as R.C.C structures, Assam type structures, Railway lines, steel warehouses, temples, flyovers, rivers etc. Nature of loads in each case is different. So, separate and detailed analysis is required for each case to have a realistic analysis. Specially, the impact of tunnelling on the structures is to be thoroughly studied and accordingly ground subsidence pattern for the particular structure is to be analyzed. If in some cases, ground subsidence pattern affects the existing structures, then preventive measures should be taken to save the structure

The conventional analysis although are simple to use, and give relatively good results, still remain limited since the different patterns are considered separately: loads are determined using usually an elastic solution, whereas movements are calculated using empirical techniques. This is the reason why the finite element method is used lately to solve complex problems such as simulating the construction sequences, soil behaviour modelling.

2. 3D FINITE ELEMENT ELASTO-PLASTIC ANALYSIS FOR PREDICTION OF GROUND SUBSIDENCE DUE TO SHALLOW TUNNELLING IN SOFT SOIL”.

To analyze the Transverse Subsidence Trough and Longitudinal Subsidence Trough of the crown of a shallow circular tunnel by 3-D finite element elasto-plastic analysis with Excavation Simulation with centre of the tunnel at a depth 10 m from Ground Surface.

2.1 Geometric Modeling.

The first step in the analysis was the creation of the Soil Domain. For this analysis, a soil domain of **30 m X 20m** is considered. Then a circular tunnel of **3 m** uniform diameter is considered at the centre of the soil domain. Thus the crown of the tunnel remains at a position **7.0 m** from Ground surface. Then the tunnel portion and the remaining soil domain are meshed by free type for finite element analysis. Then the whole soil domain along with the tunnel portion is extruded for **20** m in positive Z direction to account for the 3-D analysis. Here, Green Field Condition is assumed (i.e. no overburden on ground surface).

2.2 MaterialModeling.

Following are the properties that were assigned to the materials-

a. Modulus of Elasticity (E) = 50 MPa = 5 x 10^7 N/m^2

b. Poisson's Ratio (ν) = 0.35

c. Cohesion = 25000 N/m^2

d. Angle of internal Friction= 20°

e. Element Type = Solid Quad 4 node 42 (for 2-D analysis)= Solid Brick 8 node 45 (for 3-D analysis)

f. Unit Weight of Soil= 1800 kg/m^3

g. Acceleration due to Gravity= 9.81 m/s^2

h. Plane Strain Condition is assumed.

i. DruckerPrager yield criterion is applied.

2.3 Finite Element Discretization.

In this stage of analysis, boundary condition is defined, gravity loads are applied and the analysis is run.

The following boundary conditions were applied to the mesh:

- Base of the mesh is fully restrained in Y- direction.
- Sides of the Soil Domain are fully restrained in X-direction.
- Front and Back sides of the Soil Domain are fully restrained in Z- direction.
- Also, Extruded portion (20 m) of the soil domain in Z direction is divided into 10 equal divisions of 2 m each.

3. INTERPRETATIONOF RESULTS

3.1(a)Transverse Settlement Trough

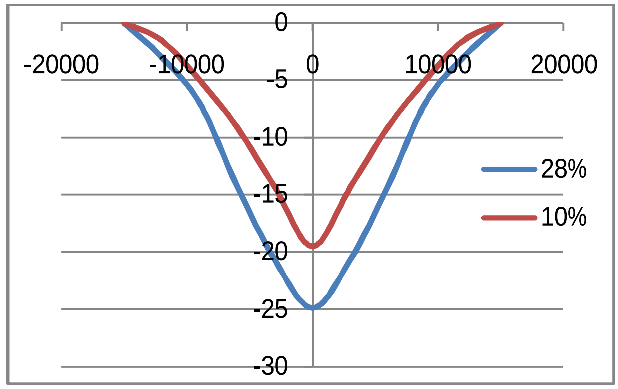


Fig 3.1(a): Variation of Transverse Settlement Troughs for varying deconfinement of 1st element of tunnel

Transverse Settlement Trough for 28% deconfinement is deeper than that of 10% deconfinement. It shows that with advancement in excavation, the ground surface experiences more subsidence which may be critical if a structure is present on the ground surface.

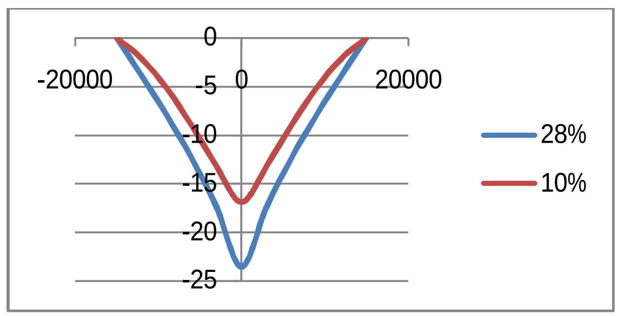


Fig 3.1(b): Variation of Transverse Settlement Troughs for varying deconfinement of 2nd element oftunnel

Transverse Settlement Trough for 28% deconfinement is deeper than that of 10% deconfinement. It shows that with advancement in excavation, the ground surface experiences more subsidence which may be critical if a structure is present on the ground surface.

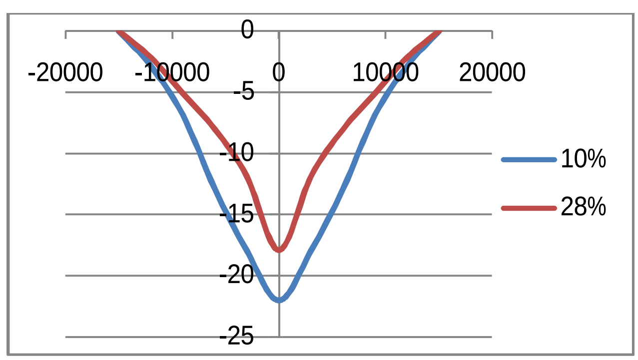


Fig 3.1(c): Variation of Transverse Settlement Troughs for varying deconfinement of 3rd element of tunnel

Transverse Settlement Trough for 28% deconfinement is deeper than that of 10% deconfinement. It shows that with advancement in excavation, the ground surface experiences more subsidence which may be critical if a structure is present on the ground surface.

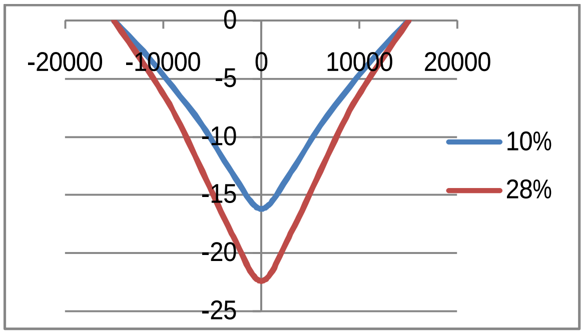


Fig 3.1(d): Variation of Transverse Settlement Troughs for varying deconfinement of 4th element of tunnel

Transverse Settlement Trough for 28% deconfinement is deeper than that of 10% deconfinement. It shows that with advancement in excavation, the ground surface experiences more subsidence which may be critical if a structure is present on the ground surface.

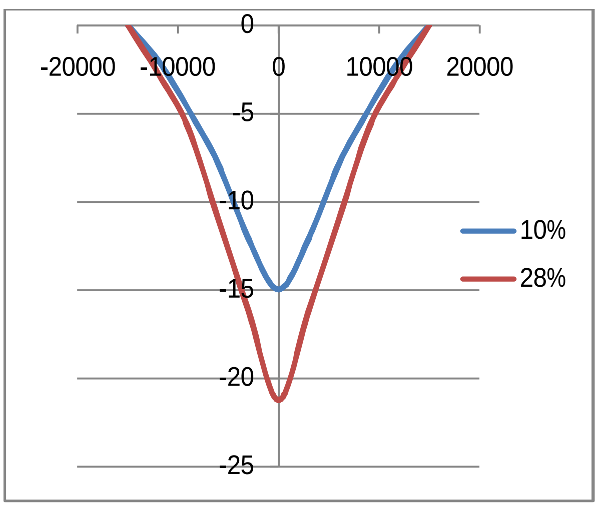
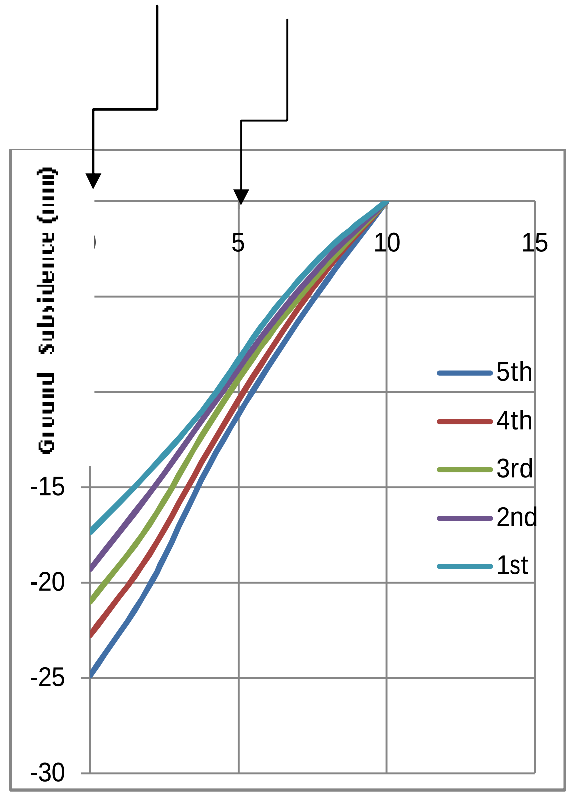


Fig 3.1(e): Variation of Transverse Settlement Troughs for varying deconfinement of 5th element of tunnel

Transverse Settlement Trough for 28% deconfinement is deeper than that of 10% deconfinement. It shows that with advancement in excavation, the ground surface experiences more subsidence which may be critical if a structure is present on the ground surface. Also, it has been observed from the above plotted Transverse Settlement Trough that, with increase in distance from the excavated face of the tunnel in longitudinal direction, amount of Ground subsidence also gets reduced.

3.2 "Longitudinal Settlement Trough for Tunnel Crown".

Tunnel Face 1st excavated face



Distance from tunnel face (m)

Fig 3.2: Longitudinal Ground Subsidence Trough for a maximum gap value of 25 mm

LEGENDS:

1st: Longitudinal Ground Subsidence trough after the excavation of First element.

2nd: Longitudinal Ground Subsidence trough after the excavation of second element.

3rd: Longitudinal Ground Subsidence trough after the excavation of third element.

4th: Longitudinal Ground Subsidence trough after the excavation of fourth element.

5th: Longitudinal Ground Subsidence trough after the excavation of fifth element.

3.3 Interpretation of Results.

5graphs are plotted in Longitudinal direction of Ground Subsidence (mm) Vs Distance from tunnel face (m) for 5 (five) steps of excavation simulation along the tunnel portion. It can be easily observed that with progress of tunnel excavation, the tunnel crown experiences cumulative effect of settlement i.e. an additional amount of settlement occurs at the face of the tunnel due to successive tunneling operation. It can be noted that maximum amount of crown subsidence is observed when 5^{th} surface of the tunnel is excavated.

It is to be specially mentioned that, above step-by-step excavation simulation process is carried out till the maximum gap value (25 mm) is reached.

4. CONCLUSION

Finite Element Method is accepted universally as a very versatile numerical tool to solve almost any type of problem. Manual calculations though gives a physical insight of the problem being handled, it is suitable only for a very small direct type problem. Moreover, in the field of geotechnical engineering, it is very difficult to understand the behaviour of sub-soil under different loading condition. The gradual improvement of finite element analysis computer code and its availability has been minimizing the complicacy of almost all types of problem. But, a certain amount of idealization and measurableengineering judgment is necessary to obtain a tractable numerical solution.

In this effort, step by step excavation simulation for a shallow tunnel has been carried out. FEM is found to be able to simulate the same and is helpful in predicting the transverse Ground Subsidence Trough. The same process may be carried out considering structure immediately above the tunnel which, in the pure sense, is a Soil Structure Interaction Problem.

5. ACKNOWLEDGEMENT

We would like to express our profound gratitude and sincere thanks to our respected guide Dr.DigantaGoswami, Associatet Professor, Department Of Civil Engineering, Assam Engineering College for his invaluable supervision, guidance and constructive suggestions throughout the course of this work and particularly for diligent scrutiny and correction of the manuscript.

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