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EVALUATION OF TUNNEL INDUCED SUBSIDENCE USING FINITE ELEMENT METHOD

[1]Shivamanth, [2]Shivakumar S. Athani, [3]Dr. M. K. Desai and [4]Dr. G. R. Dodagoudar

[1]Research Scholar, S V National Institute of Technology, Surat, Gujarat, India 395-007.

[2]Post Graduate Student, S V National Institute of Technology, Surat, Gujarat, India 395-007.

[3]Assistant Professor, S V National Institute of Technology, Surat, Gujarat, India 395-007.

[4]Professor, Indian Institute of Technology, Madras, Chennai, India 600-036.

ABSTRACT

The present study illustrates the modeling of underground tunnel for subsurface analysis of site using finite element methods. In particular the effect of overburden weight, the nature of the contact between the tunnel and surrounding soil and the geometry of tunnel with respect to the direction of tunneling on the subsidence pattern has been investigated. The software used for the analysis is PLAXIS. PLAXIS is a finite element program that is designed for the applications of geotechnical engineering in which soil models are used for simulating the soil behavior. The tunnel has been modelled in PLAXIS 2D under different construction stages and different operating conditions. A tunnel excavation having diameter of 5m which is lying 25m below the ground surface is considered for performing the analyses. The same is modeled in PLAXIS and the subsidence curve is generated. The result obtained from the finite element analysis is compared with the closed form solution. The subsidence curve is generated considering two different conditions viz: in presence of clay bed of thickness 10m lying on top of the excavation and without clay bed. Also comparative study of the subsidence pattern has been carried out.

Keywords: Closed Form Solution, Finite Element Method, PLAXIS, Subsidence Curve, Tunnel

I. INTRODUCTION

Tunnels are very important for both in geotechnical engineering and daily life of the people. Tunnels are constructed for different purposes such as transportation of people, materials, water conveyance and storage. The duty of a geotechnical engineer is to design tunnels which meet the needs in a safe and economic manner. Tunnels are constructed for hundreds of years but in engineering judgment the design of tunnels has improved greatly with analytical solutions proposed by engineers and with the developing computer technology.

In the analysis PLAXIS 2D Tunnel geotechnical finite element package was used. This program allows the user to define the actual construction stages of a tunnel construction. Analysis using PLAXIS mainly consists of three stages namely input stage, calculation stage, post processing stage. Input stage includes model design, assigning the material properties, boundary conditions, loading and meshing. In the present analysis, 15 node triangular elements are used for meshing. The calculation stage requires selection of analysis type such as

Plastic, Dynamic, Consolidation and Phi-C reduction. The loads assigned are activated here and analyzed. In the post processing stage, plotting of subsidence curves has been calculated.

II. METHODOLOGY

2.1 Initial phase: Initial Conditions

The K_0 procedure is used to generate initial effective stresses. The water pressures are generated on the basis of general phreatic level. In this phase soil profile is activated and without clay bed is deactivated.

2.2 Phase 1: Tunnel (without clay bed):

Plastic drained is used as calculation type. Both the soil cluster inside the tunnel and the without clay bed are deactivated in this phase.

2.3 Phase 2: Tunnel (with clay bed layer):

Plastic drained is used as calculation type. The soil cluster inside the tunnel is deactivated and the clay bed layer is activated in this phase. A staged construction calculation is needed in which the tunnel with clay bed layer is activated and the soil clusters inside the tunnel are deactivated. Deactivating the soil inside the tunnel only affects the stiffness of soil, the strength and the effective stresses. Without additional input the water pressures remain.

III. INPUT PARAMETERS

3.1 Materials - Soil and Interfaces - Mohr-Coulomb

Identification		C06 - Clay	soft clay
Identification number		1	2
Drainage type		Undrained (B)	Undrained (B)
Colour			
Comments			
γ_{unsat}	kN/m ^{3}	15.00	15.00
γ_{sat}	kN/m ^{3}	18.00	18.00
Dilatancy cut-off		No	No
e_{init}		0.5000	0.5000
e_{min}		0.000	0.000
e_{max}		999.0	999.0
Rayleigh α		0.000	0.000
Rayleigh β		0.000	0.000
E	kN/m ^{2}	3000	2000
ν (nu)		0.3000	0.3000
G	kN/m ^{2}	1154	769.2
E_{oed}	kN/m ^{2}	4038	2692

Identification		**C06 - Clay**	**soft clay**
c_{ref}	kN/m ^{2}	5.000	5.000
φ (phi)	°	0.000	0.000
ψ (psi)	°	0.000	0.000
V_s	m/s	27.46	22.42
V_p	m/s	51.37	41.94
Set to default values		No	No
E_{inc}	kN/m ^{2}/m	391.0	391.0
y_{ref}	m	3.000	3.000
c_{inc}	kN/m ^{2}/m	2.000	2.000
y_{ref}	m	3.000	3.000
Tension cut-off		Yes	Yes
Tensile strength	kN/m ^{2}	0.000	0.000
Undrained behaviour		Standard	Standard
Skempton-B		0.9783	0.9783
v_u		0.4950	0.4950
$K_{w,ref}$ / n	kN/m ^{2}	112.5E3	75.00E3
$C_{v,ref}$	m ^{2}/day	0.04038	0.02692
Strength		Manual	Manual
R_{inter}		0.6000	0.6000

Identification		**C06 - Clay**	**soft clay**
δ_{inter}		0.000	0.000
K_0 determination		Manual	Manual
$K_{0,x}$		0.5000	0.5000
Data set		Standard	Standard
Type		Coarse	Coarse
< 2 μm	%	10.00	10.00
2 μm - 50 μm	%	13.00	13.00
50 μm - 2 mm	%	77.00	77.00
Set to default values		No	No
k_x	m/day	0.1000E-3	0.1000E-3
k_y	m/day	0.1000E-3	0.1000E-3
$-\psi_{unsat}$	m	0.000	0.000
e_{init}		0.5000	0.5000
c_k		1.000E15	1.000E15

INPUT PARAMETERS FOR LINING MATERIAL

3.2 Materials – Plates

Identification		C06 - Lining
Identification number		1
Comments		
Colour		
Material type		Elastic
Isotropic		Yes
EA_1	kN/m	14.00E6
EA_2	kN/m	14.00E6
EI	kN m^2/m	143.0E3
d	m	0.3501
w	kN/m/m	8.400
ν (nu)		0.1500
Rayleigh α		0.000
Rayleigh β		0.000

IV. ANALYSIS AND RESULTS

4.1 Mesh Generation

It is expected that stress concentrations occur around the tunnel, therefore the mesh is refined in those areas. The default global coarseness parameter (medium) is adopted. The generated mesh is displayed in the output program is shown in the Fig 1.

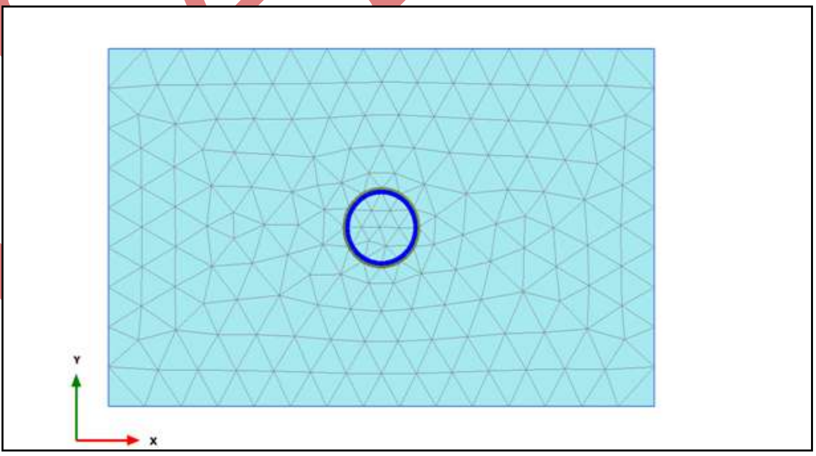

Fig 1: Finite Element Mesh for Tunnel

Using the above input parameters, the initial phase (without clay bed) is modeled and analyzed using PLAXIS and corresponding total displacement is calculated. The total displacement is found to be 0.03322 m.

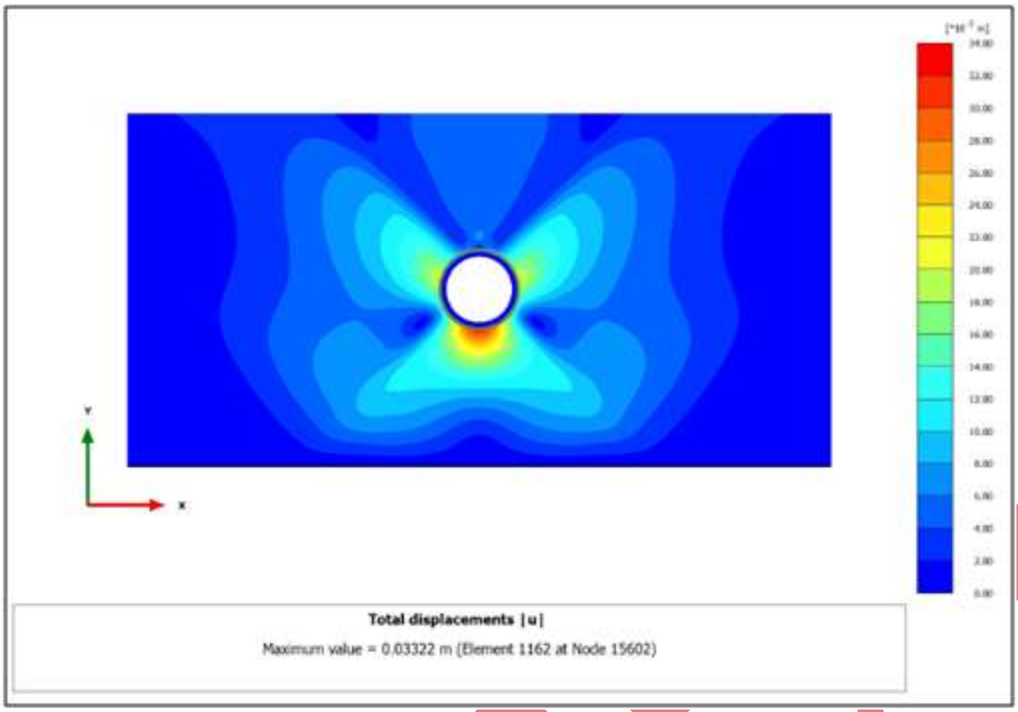

Fig 2: Displacement Contour

V. ANALYTICAL METHOD

5.1 Volume Loss and Subsidence Curve (Without Clay Bed)

The volume loss method is a semi-empirical method based partially on theoretical grounds. The method introduces, although indirectly, the basic parameters of excavation into the analyses (these include mechanical parameters of a medium, technological effects of excavation, excavation lining etc) using two comprehensive parameters (coefficient *k* for determination of inflection point and a percentage of volume loss *VL*). These parameters uniquely define the shape of subsidence trough and are determined empirically from years of experience.

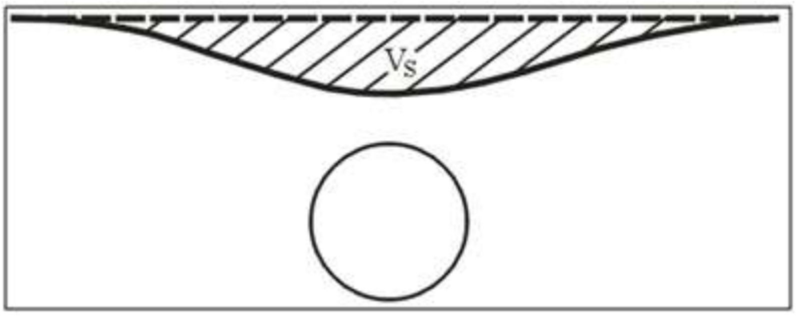

Fig 3: Settlement expressed in terms volumes

The maximum settlement S_{max}, and location of inflection point L_{inf} are provided by the following expressions:

$$L_{inf} = k.Z$$

$$S_{max} = \frac{AVL}{100} \cdot \frac{1}{\sqrt{2.\pi}.L_{inf}}$$

Where:

A - excavation area

Z - depth of center point of excavation

k - coefficient to calculate inflection point (material constant)

VL - percentage of volume loss

The horizontal displacement at a distance *x* from the vertical axis of symmetry is given by:

$$S_i = S_{max} . e^{\left(\frac{-x_i^2}{2.L_{inf}^2}\right)}$$

Where:

S_i - settlement at point with coordinate x_i

S_{max} - maximum terrain settlement

L_{inf} - distance of inflection point

The value of S_{max} obtained from Closed form solution is 0.03389 m and the corresponding volume loss calculated is found to be 1.081%.The subsidence curve obtained without clay bed is shown below:

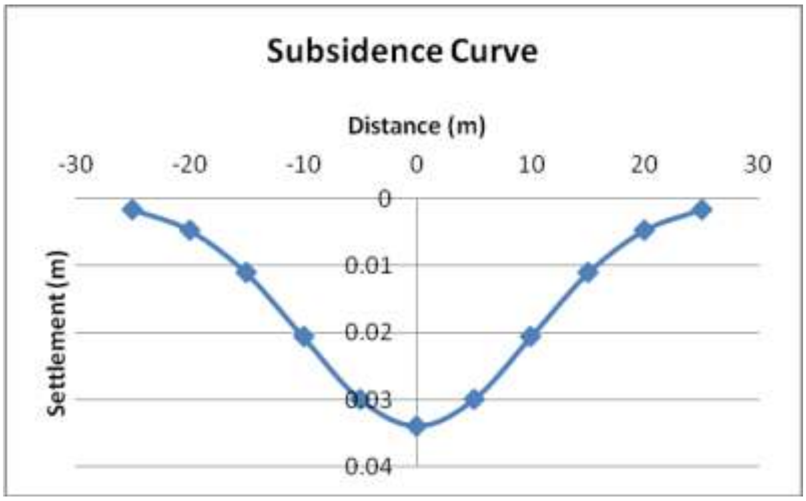

Fig 4: Subsidence Curve

VI. MODELLING THE SECOND PHASE (with clay bed layer)

The problem is modelled when a clay bed of thickness 10m lying on top of the excavation using PLAXIS. The material is assumed to be failed by Mohr- Coulomb model. The tunnel excavation along with the clay bed is shown below:

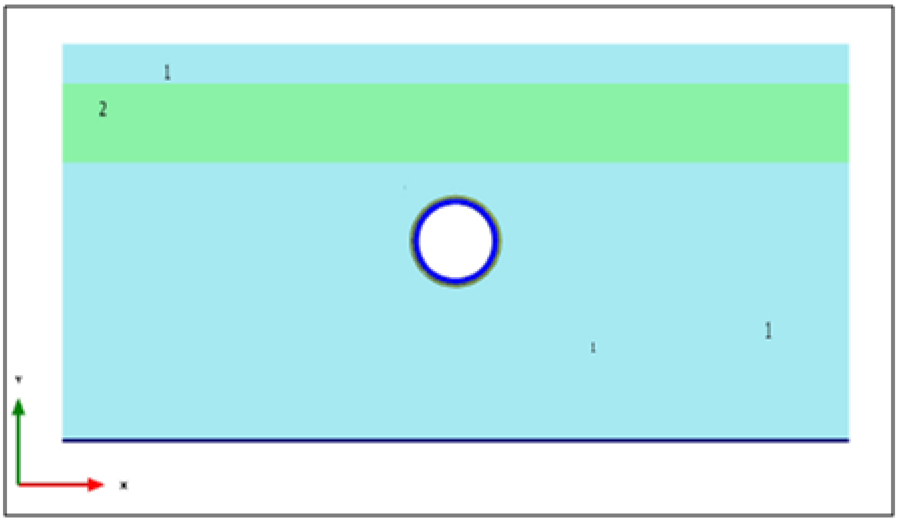

Fig 5: Tunnel excavation with clay bed layer

The total displacement obtained (with clay bed layer) is found to be 0.03332 m. The total displacement diagram is shown below:

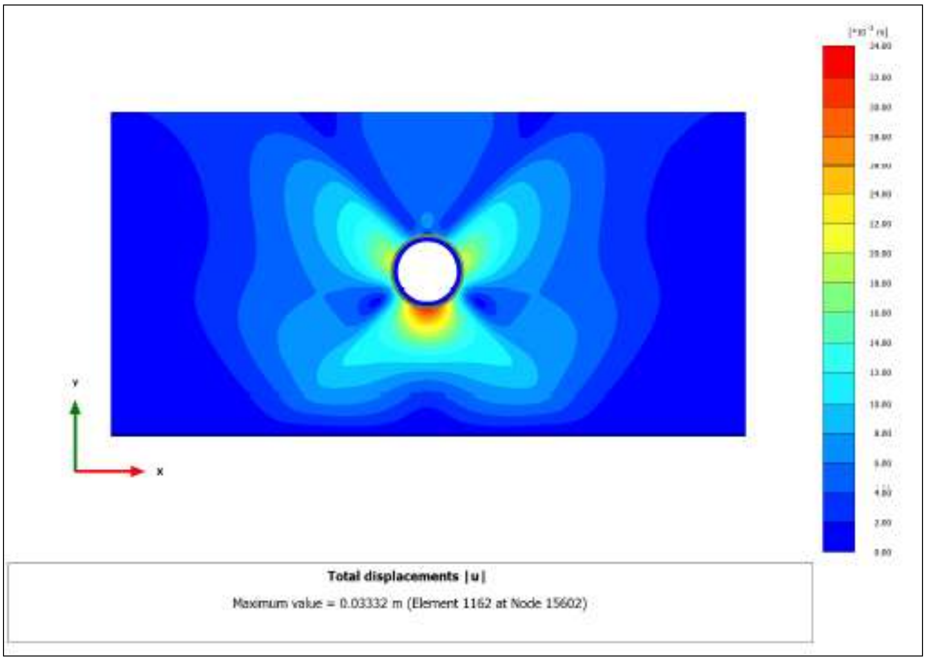

Fig 6: Displacement Contours in presence of Clay Liner

VII. CONCLUSION

The given problem is modeled in PLAXIS with and without the clay bed layer. The subsidence obtained when there is no clay bed layer is compared with the closed form solution. The total displacement without clay bed layer was found to be 0.03322 m and that with clay bed layer was found to be 0.03332 m.

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