NUMERICAL ANALYSIS OF GEOSYNTHETIC REINFORCED SOIL ABOVE A TUNNEL

S.E. Ghoreishi Tayyebi[1], M.R. Babatabar[1] & A. Tahmasebi poor[2,*]

[1]Islamic Azad University, Ayatollah Amoli Branch, Departments of Civil Engineering, Amol, Iran
[2]Khazar ab Consulting Engineers Company

*Email: abbas_tahmasebipoor@yahoo.com

ABSTRACT

In this paper numerical experiments are conducted to investigate the effect of geosynthetic reinforced soil above a tunnel on stability of system. A series two dimensional finite element analyses under plane strain condition was performed to study stability of soil-geosynthetic-tunnel system. The effectiveness of geosynthetic reinforced soil above a tunnel is affected by many factors such as depth of single layer, tensile stiffness and number of reinforcement layers.

In this paper, a systematic parametric study was conducted to study effect of these parameters on improving the stability of tunnel headings and reducing ground movements in sand.

Based on the results of the study, the use of this system reduces the settlements at the tunnel heading and ground surface. It can be concluded that when a single layer of reinforcement is used, there is an optimum depth at which settlements are maximum. Settlements reduce with increase in axial rigidity (E.A) of reinforcement and stability of the tunnel face is improved too. Also settlements reduce with increase in number of reinforcement layers but there is an optimum value for number of reinforcement which increases more than this certain value has not significant effect on reduction of settlements.

Keywords: *finite element, reinforcement, tunnel, geosynthetic*

1. INTRODUCTION

In most major cities, the demand for tunnel construction for various purposes, such as transportation or sewage systems, is increasing due to space limitations and environmental concerns. Ground surface settlement due to tunneling in soft ground is a major concern in all aspects of tunnel design. Tunnel displacement causes deformation of the ground between the tunnel and the ground surface and hence results in subsidence at the ground surface. The surface settlement is caused by a combination of ground loss at the tunnel, which includes the ground loss at the tunnel face, convergence of the tunnel cavity and the closure of the physical gap between the concrete lining and the ground. The effect of settlement due to shallow tunneling is hazardous to nearby buildings, infrastructures and existing services.

A number of viable foundation support solutions exists that help to confront the problem of placing structures over tunnel.

Reinforcements such as soil nails can be applied for stabilizing the tunnel heading.

Grasso et al. (1989) discussed the use of reinforcement for stabilizing the rock mass during the excavation. In order to find the required soil nail density, Barley and Graham (1997) performed a series of pull-out tests by varying the material (steel or fiber glass) of the soil nail, the borehole diameter, the minimum fixed length and the grouting material. Peila (1994) conducted a series of three-dimensional finite element analyses to study the stabilizing effects resulting from core reinforcement by soil nails. Dias et al. (1998) compared the behavior of a tunnel face reinforced by nails in an analytical model with a numerical model.

A new method of reinforcing tunnel excavation and reducing the effect of ground loss at the tunnel is to create a boundary of high stiffness between the ground surface and the tunnel. In order to enhance soil property before tunneling, steel pipes can be jacked over the projected tunnel crown either in a gate typed or horse-shoe typed arrangement to form a layer of reinforced ground between the proposed tunnel core and the ground surface (Tan et al. (2003)).

Matsumoto et al. (2001) described the usage of large diameter steel pipes jacked into the tunnel periphery and then grouted at the Satsuma Tagami Tunnel in Japan.

Yoo and Shin (2000) conducted a parametric study on the effect of reinforcing layouts on the deformation behavior of the tunnel face and drew a conclusion that there existed an optimum reinforcing layout to reduce the deformation of the tunnel for a given tunnel geometry and ground condition.
One of the more economic methods currently being proposed to prevent collapse of these tunnels under road and railway embankments is to place a reinforcing geosynthetic at the base of the structure.
Geosynthetics have frequently been used for soil reinforcement world wide. Besides their application to the construction of retaining structures and stability of soft grounds, geosynthetic reinforced soils have also been utilized for bridge cavities.
For the stability of a reinforced soil layer overlying a cavity, Giroud (1982) analyzed the load-carrying capacity using the tensioned membrane theory. Bonaparte and berg (1987) utilized the tensioned membrane theory with a consideration of the soil arching effect. This approach was further extended by Giroud et. al. (1990) for analysis and design of soil geosynthetic systems overlying voids.
Briancon and Villard (2008) have developed a new approach to improve the usual design methods. Their method is based on the existing methods to describe behavior of the geosynthetic over the cavity (membrane effect) but takes into account the geosynthetic behavior in anchorage areas and the increase in stress at the edge of the cavity.
In this paper, a parametric study conducted on the effect of geosynthetic reinforcing laid outs on stability of soil over a circular tunnel.
A series of two-dimensional finite element analysis under plane strain condition was carried out with PLAXIS (version8.2) code to study of these systems.

2. MATERIAL AND NUMERICAL MODELING

The finite element method is widely accepted numerical method for analysis and design in almost all branches of engineering. PLAXIS is a finite element code for soil and rock analyses, originally developed for analyzing deformation and stability in geotechnical engineering projects. The geometry of the modeled problem is presented in Fig.1. The soil was assumed to be homogenous and isotropic.
An elastic-plastic Mohr-coulomb failure criterion was used to model the behavior of cohesion less overburden soil.
To prevent collapse of overburden soil into tunnel, a concrete lining has been considered in model.

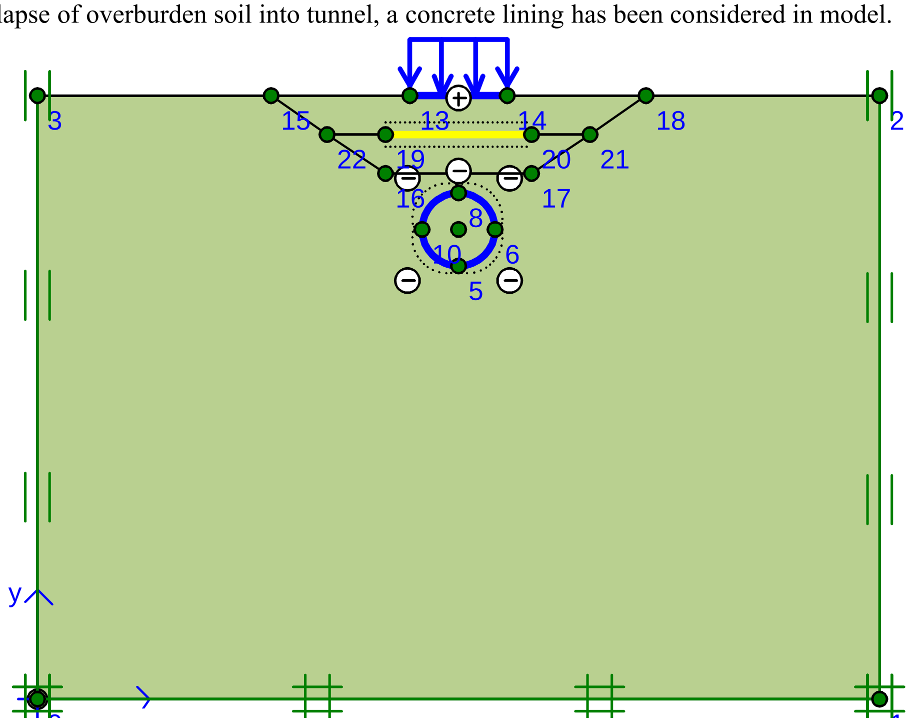

Fig.1. Geometry of multi geosynthetic reinforced soil above a tunnel.

The plain strain condition and 15-node triangular elements were used for analysis. Reinforcement layers were modeled using the geogrid element already into the program. To model the slip between the soil and reinforcement these elements are combined with interfaces. Interfaces were placed on both sides of the geosynthetic, allowing the geosynthetic to move independently of the surrounding soil. The interface friction angles were given values equal to

two-thirds of the friction angle of the soil. This allowed movement along the interface, but no separation between the soil and geosynthetic.
Geosynthetic are slender objects with a normal stiffness but with no bending stiffness. Reinforcement can only sustain tensile forces and no compression.
When 15-node soil elements are employed the each reinforcement element is defined by 5-nodes.
The finite element mesh of geometry is presented in Fig.2.

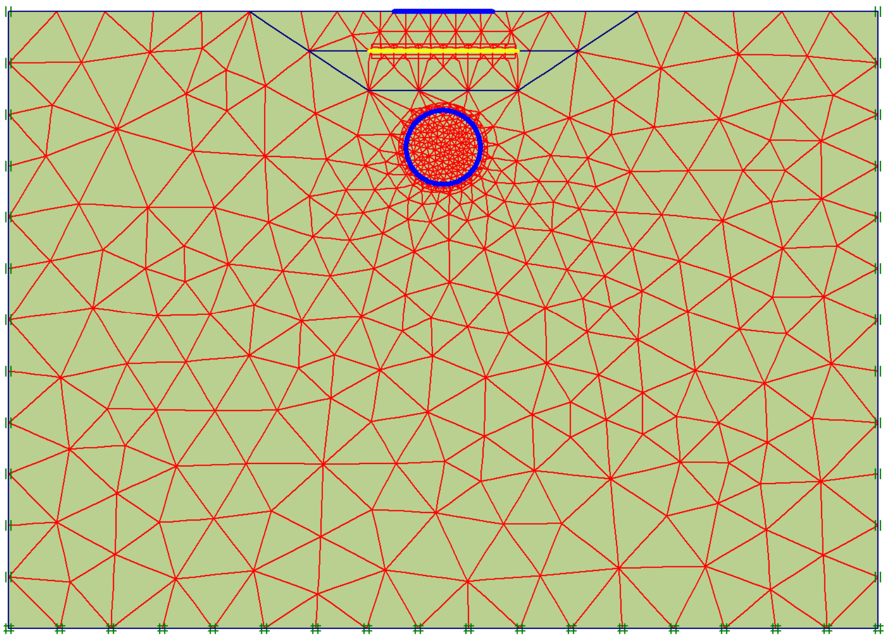

Fig.2. Finite element mesh of the geometry

The only material property of reinforcement is the elastic normal (axial) stiffness EA.
The soil parameters used in the numerical analysis are listed in Table.1.

Table.1. material properties used in finite element analyses

Parameter	value
Angle of internal friction (degree)	35
Cohesion (KPa)	1
Modulus of elasticity (KPa)	20000
Poisson′s ratio	0.3
Unit weight (KN/m^3)	19
Angle of dilatancy (degree)	0

To minimize the boundary effect, the vertical boundary at the far end, on the left and right-hand side, is set 35m away from the center of tunnel that are assumed to be free in the vertical direction and restricted in horizontal direction.
The bottom horizontal boundary is restricted in both the vertical and horizontal directions.
In the present study, a series analyses was carried out on this model to investigate the effect of:

a) Depth of single layer of reinforcement.
b) Tensile stiffness of reinforcement.
c) Number of reinforcement layers.

On stability of geosynthetic reinforced soil above tunnel

3. EFFECT OF DEPTH OF SINGLE LAYER OF REINFORCEMENT

In order to investigate the effect of this parameter on maximum settlement of ground surface and head of tunnel, single layer of geosynthetic with tensile stiffness equal to 500KN/m and length of 12m laid out in different depths. The ratio of depth of geosynthetic layer(y) to thickness of over burden of tunnel (h), is called "depth ratio ".

Fig.3. illustrates the effect of depth of single reinforcement layer on maximum settlement of ground surface and head of tunnel for uniformly distributed load (p) equal to 400KN/$m^{2.}$

It can be seen that with increase in depth of reinforcement, maximum settlement of ground surface and head of tunnel first increases and then decreases. The graphs clearly show that there is an optimum depth of reinforcement at with settlement is maximum i.e. minimum reduction in settlement is there.

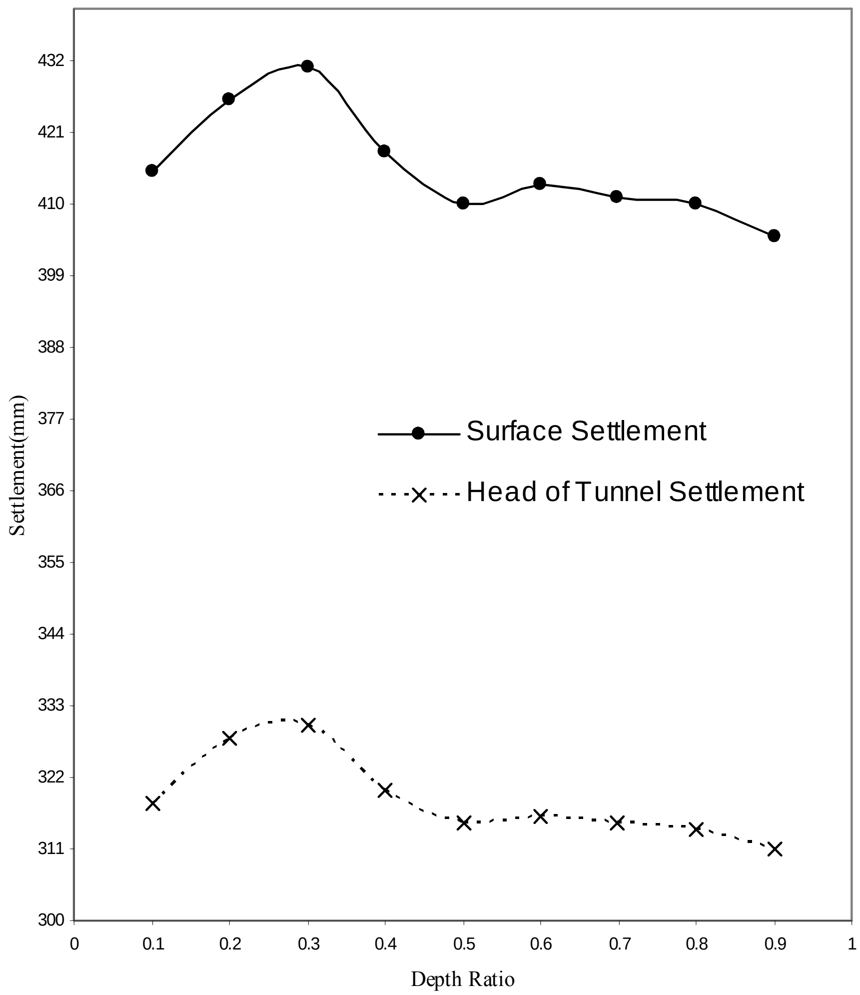

Fig.3. effect of depth of single layer of reinforcement on maximum settlement (EA=500KN/m, P=400KN/m^2, L=12m).

Fig.4. shows the variations of maximum tensile strain with depth in unreinforced soil for uniform intensity loads equal to 300, 400 and 500KN/m^2.

Variations of settlement shown in figure mean that in depth with minimum tensile strain, the reinforcement has minimum effect on reduction of settlements.

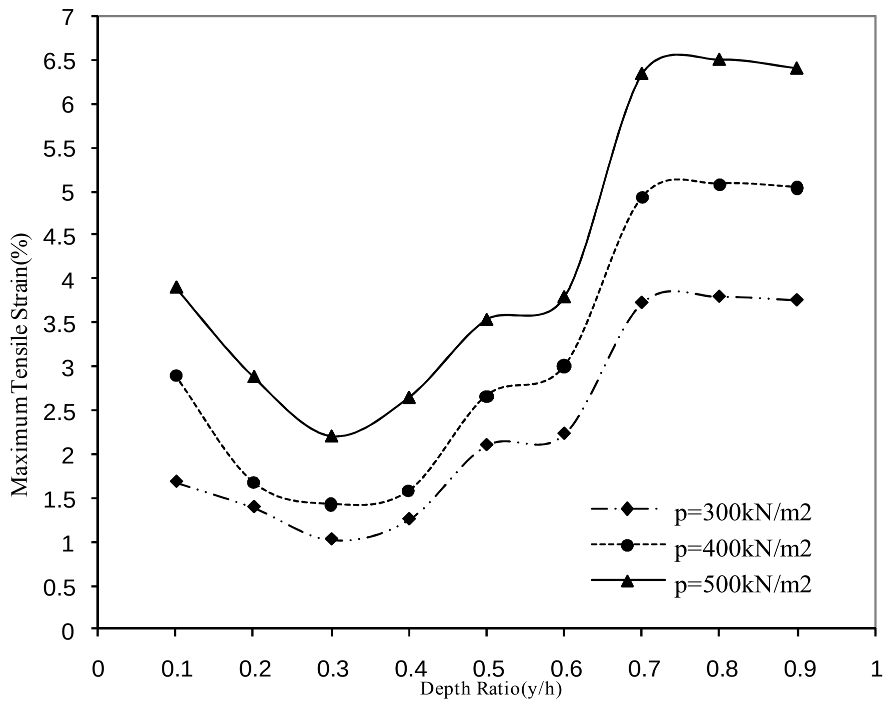

Fig.4. variations of maximum tensile strain with depth in unreinforced soil (P=300, 400 and 500 KN/m^2)

4. EFFECT OF TENSILE STIFFNESS OF REINFORCEMENT

The effect of tensile stiffness of the single layer geosynthetic on maximum settlement of ground surface and head of tunnel has also been studied for different stiffness equal to 20, 100, 500 and 1000KN/m.
Fig.5. show the relation between depth and maximum settlement for different tensile stiffness of reinforcement and for load equal to 500KN/m^2. In the analyses, the length of geosynthetic layer has been choosen 12m.
It is seen that maximum settlement reduces with increase in stiffness of the reinforcing layer, because the load carried by the reinforcement is in proportion to its stiffness. Thus, stiff reinforcements would attract high loads compared to less stiff reinforcements.

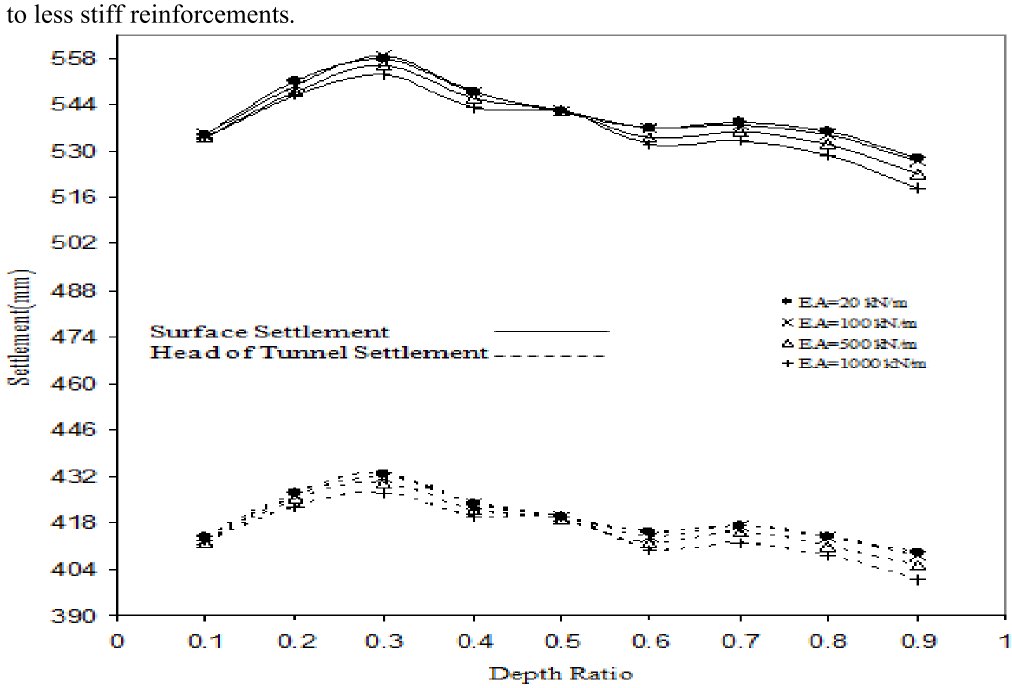

Fig.5. Effect of reinforcement stiffness on maximum settlements (P=500KN/m^2, L=12m).

Fig.6. illustrates the relation reinforcement stiffness and maximum settlement of ground surface for load equal to 500KN/m^2 and different depth ratios.
Thus when geosynthetic laid out near the ground surface, the mobilized tension in reinforcement layer would decrease and it would attract lower loads, hence increase in geosynthetic tensile stiffness has lower effect for smaller depth ratios.

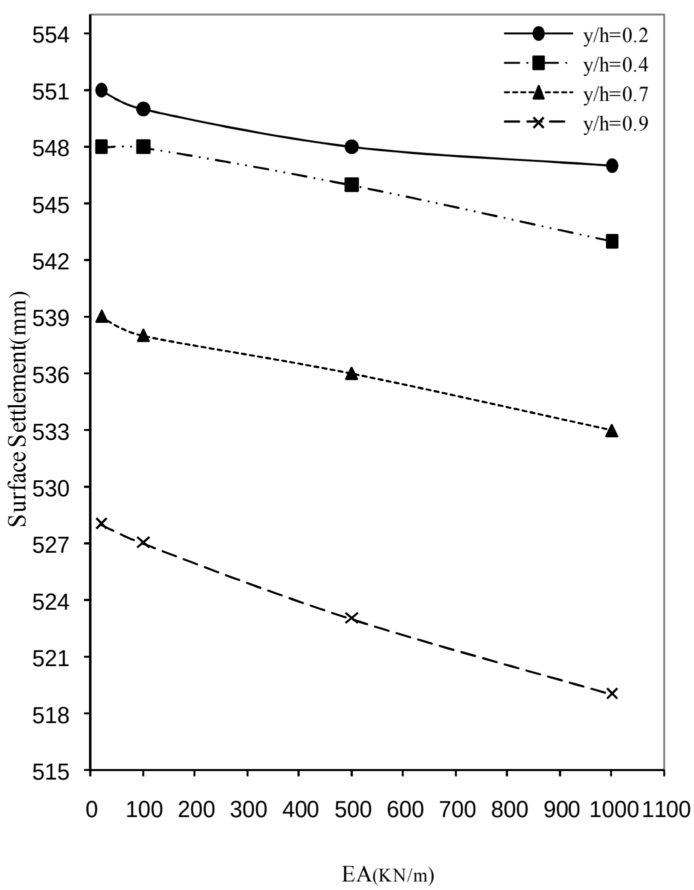

Fig.6. effect of geosynthetic tensile stiffness on maximum settlement of ground surface for different depth ratios (P=500KN/m^2).

5. EFFECT OF NUMBER OF REINFORCEMENT LAYERS

For investigate the effect of number of reinforcement layer on maximum settlements and reduction of stresses, a series analyses was carried out on model with different number of geosynthetic layers and for tensile stiffness equal to 50, 500 and 1000KN/m.
In the all analyses, the length of reinforcement layer was constant and equal to 12m.
Fig.7. shows the effect of number of geosynthetic layer on maximum settlements of ground surface and head of tunnel for different tensile stiffness.
It can be seen that the settlements reduce with increase in number of reinforcement layers and then become approximately constant even though there is further increase in number of geosynthetic layers. It clearly indicates that there are reductions in settlement up to maximum extent at that particular stiffness.
This is because the depth of influence under load is finite; hence increase of geosynthetic layers has not significant effect on reduction of settlements.
Also Fig.7.shows that this optimum number of reinforcement layers is more in case of reinforcement with low stiffness than that of the higher stiffness.

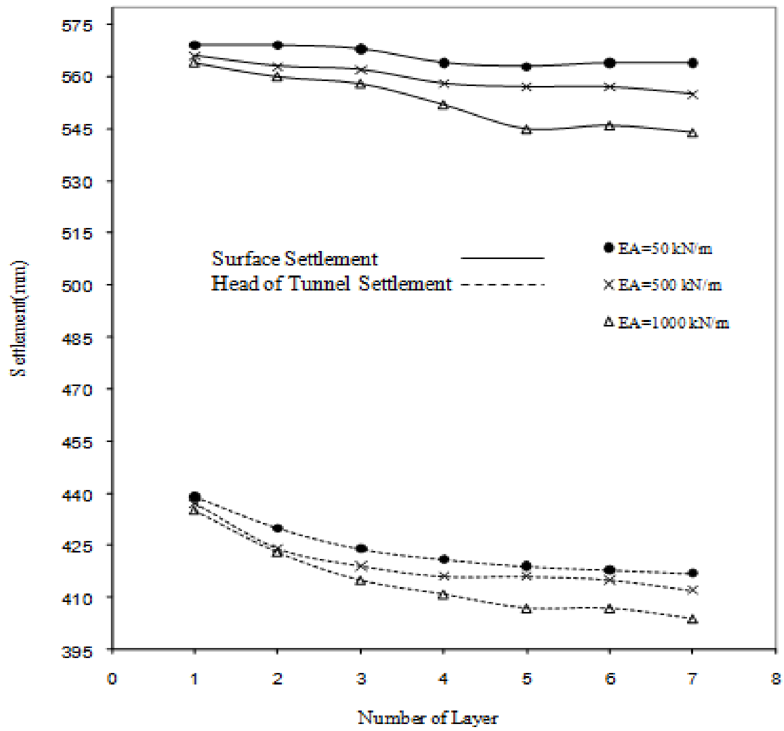

Fig.7. Effect of number of reinforcement layers on maximum settlement (P=100KN/m^2).

Fig.8. illustrates the effect of number of reinforcement layers on reduction of vertical stresses at the section across the center of tunnel. The graphs show clearly that vertical stresses decrease with the increase in the number of reinforcement layers. But in depths near the head of tunnel, stresses decrease. This is because of arching action of soil above the tunnel. Arching causes a reduction in vertical stresses. In the case of a tunnel under a fill, arching effect reduces the stress and tension in the reinforcement transfer part of the stress to adjacent stable ground.

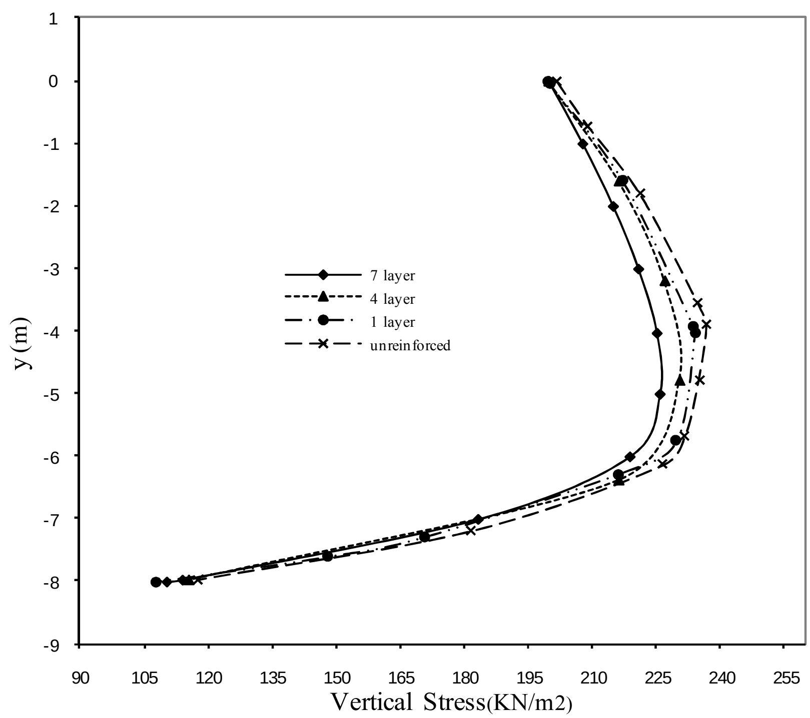

Fig.8. Effect of number of reinforcement layers on vertical stress at centerline section of soil above a tunnel (P=200KN/m^2).

6. CONCLUSIONS

The stability of geosynthetic reinforced soil above a tunnel was studied using a two dimensional finite element method. Based on the parametric study the following conclusions can be made:

When single layer of geosynthetic used to reinforcing soil above a tunnel, there is an optimum depth of reinforcement at which minimum reduction in settlement is achieved.
The stability of the tunnel face is improved with increasing axial rigidity. The effect of increase in stiffness of the reinforcement has been found to reduce the maximum settlements of ground surface and increases for greater values of depth ratios.
With increase in number of reinforcement layers, maximum settlements of ground surface and head of tunnel have been found to reduce. But efficiency of system diminishes when optimum number of geosynthetic layers is reached. This optimum value is greater in case of reinforcement with low stiffness.
Also the use of soil reinforcement system reduces the magnitude of vertical stress at the tunnel heading. This reduction of vertical stresses increase with enhancement in number of reinforcement layers.

7. REFERENCES

[1]. Grasso. P., Mahtab. A. and Pelizza. S., (1989), “Reinforcing a Rock Zone for Stabilizing a Tunnel in Complex Formations”. International Congress on Progress and Innovation in Tunnelling. Toronto, Volume 2, pages 663–670.
[2]. Barley. A.D. and Graham. M., (1997), “Trial Soil Nails for Tunnel Face Support in London Clay and the Detected Influence of Tendon Stiffness and Bond Length on Load Transfer”. Journal of Ground improvement geosystems— densification and reinforcement. Thomas Telford, pages 433–444.
[3]. Pelia D., (1994), “A Theoretical Study of Reinforcement Influence on the Stability of a Tunnel Face”, Journal of Geotechnical and Geological Engineering, Volume 12, Pages 145–168.
[4]. Dias. D., Kastner. R., Subrin. D., Wong. H. and Dubois. R., (1998), “Behaviour of a Tunnel Face Reinforced by Bolts: Comparison between Analytical-Numerical Models”. Proceeding Of the Geotechnics of Hard Soils — Soft Rocks.Balkema, pages 961–972.
[5]. Tan, W.L. and Ranjith, P.G., (2003), “Numerical Analysis of Pipe Roof Reinforcement in Soft Ground Tunnelling”16th ASCE Engineering Mechanics Conference, University of Washington.
[6]. Matsumoto, Y., Kurose, N., Inoue, T., Kurazono, M. and Nodomi, K. (2001). “New pre support method using pipe roof by semi shield and chemical grouting for shirasu fill”, Modern Tunnelling Science and Technology, Adachi et al. (eds.), Swets & Zeitlinger, pp.751-756.
[7]. Yoo .CS, and Shin HK, (2000), “Behavior of Tunnel Face Pre-reinforced with Sub-horizontal Pipes”. Proceeding Of Geotechnical Aspect of Underground Construction in Soft Ground. Balkema, Pages 441–446.
[8]. Giroud, J.P. (1982), “Design of Geotextile Associated With Geomemebrances”, Proceedings Of The 2nd International Conference On Geotextiles, Las Vegas, NV, Pages 37-42
[9]. Bonaparte, R. and Berg, R. R. (1987), “The Use of Geosynthetics to Support Roadways Over Sinkhole Prone Areas”, In Proceedings of the 2nd Multidisciplinary Conference on Sinkholes and the Environmental Impacts of Karst. Orlando, FL, Pages 437-445.
[10]. Giroud, J.P., Bonaparte, R., Beech, J.F. and Gross, B.A. (1990), “Design of Soil Layer- Geosynthetic Systems Overlying Voids”, Journal of Geotextile and Geomembranes, Volume 9, Issue 1, Pages 11-50.
[11]. Briancon,L.,Villard, P., (2008), “Design of Geosynthetic Reinforced Platforms Spanning Localized Sinkholes”, Journal of Geotextile and Geomembranes, Volume 26, Issue 5, Pages 416-428
[12]. Brinkgreve, R.B.J., et al. (1998), “Plaxis Finite Element Code for Soil and Rock
[13]. Analyses”, Delft University of Technology, the Netherlands.