International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 08, August-2015

Influence of Tunneling on Adjacent Existing Pile Foundation

Mr. K. Raja
Assistant Professor,
Department of Civil Engineering,
N.S.N. College of Engineering and Technology,
Karur, India

Dr. K. Premalatha
Professor,
Department of Civil Engineering,
College of Engineering, Guindy, Anna University
Chennai, India

Mr. S. Hariswaran
Assistant Professor,
Department of Civil Engineering,
Agni College of Engineering and Technology,
Chennai, India

***Abstract*— One of the important issues of tunneling in urban areas is the assessment of the impact on adjacent buildings of tunnel construction. Many high rise buildings are supported by pile foundations in major cities. Tunneling activities carried out adjacent to these pile foundations invariably cause ground movements, which in turn will impose axial and lateral forces on the pile foundations. The study focuses on the estimation of ground movements induced by tunneling (both vertical displacements and horizontal displacements) and the imposition of these soil movements on the pile and computation of the consequent pile responses. Tunneling induced behavior of piles was estimated using PLAXIS software. A parametric study was carried out for short pile in sand. Based on the parametric study, design charts were developed for short piles to estimate the tunneling induced behavior of pile easily.**

***Keywords*— Tunneling, Free field ground movements, Settlement, Short pile**

I. INTRODUCTION

In recent years, there has been an increase in infrastructure development in highly populated or urban area. There transportation plays a vital role to facilitate the people to move from one place to other. In order to meet the demand for transportation in urban area several projects have been undertaken including road, rail transport on flyovers and underground tunnels. Apart from transportation numerous utility lines are also used below the ground level.

Excavations below ground level causes relaxation of insitu stress i.e. ground loss. Tunneling is also one form of excavations which cause ground losses. In the highly populated or urban areas the underground excavation for tunneling is carried adjacent to the high rise buildings. Therefore in urban areas, the performance of nearby piled foundations was affected by tunneling activities. Necessary steps are required to assess the responses of pile foundation due to tunneling at various depths and to prevent the pile from deformation and settlement.In many large heavily populated cities, tunnel excavation is very close to the adjacent buildings. This induces vertical and lateral soil movement on piles, which in turn induce axial responses such as axial force and settlement. It also induces lateral responses such as pile bending moment and deflection.

This present study focuses on the estimation of ground movements induced by tunneling and the imposition of these soil movements on the pile and computation of the consequent pile responses.

II. METHOD OF ANALYSIS

The fast growing population and the scarcity of land in the urban areas needs diversification in traffic. By providing subways and tunnels in these urban areas, technically the traffic can be made feasible and viable. While constructing the tunnels and subways in the urban areas, it may happen to cross near the high rise buildings. When these tunnels are to be executed adjacent or below the foundations of the adjacent buildings, the relaxation in stress causes ground loss, which in turn affects the behavior of pile foundation .Necessary steps are required to assess the responses of pile foundation due to tunneling at various depths and to prevent the pile from deformation and settlement. Many solutions are available to predict the ground movements they are analytical, empirical and numerical solutions. Software tools are also used to predict these ground movements. Some of them are PLAXIS and Xdisp. Ground movement profile of a tunnel depends on the ground loss. Despite other factors, the major factor that influences the ground loss is the installation technique. Experiences in tunneling technology advocate to do the tunnel work with minimum ground loss. The reported ground loss is 1-3%. The present analysis is carried out in two stages, they are

STAGE 1: Prediction of Free Field Ground Movements

STAGE 2: Response of Pile Foundation for Ground Movement

III. PREDICTION OF FREE FIELD GROUND MOVEMENTS

The major ground movements discussed here are surface settlement, subsurface settlement and lateral displacement. These ground movements can be estimated using various methods such as empirical method, analytical method and numerical method. For the present analysis the input parameters reported in literature for Heathrow Express Trial Tunnel in clay soil, central London was used. The ground movements estimated using different methods were compared with the observed ground movements.

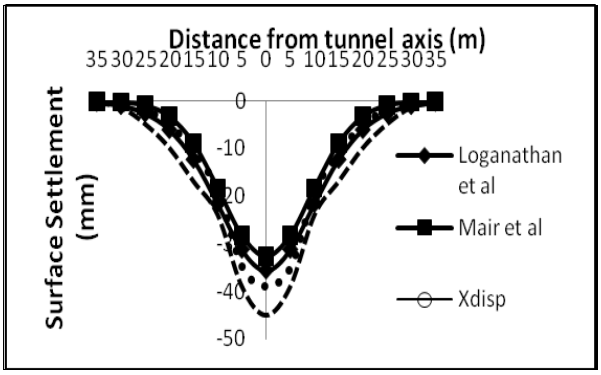

Fig-1 Surface settlement

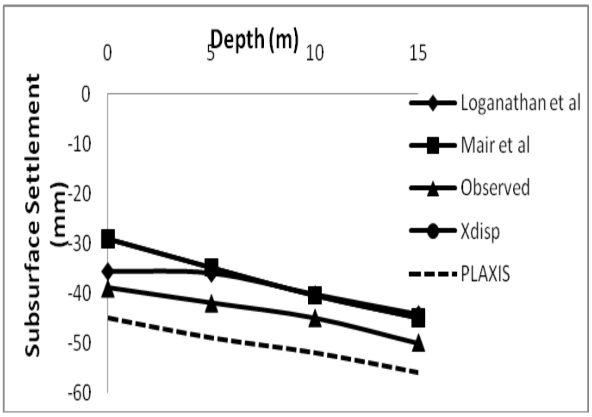

Fig-2 Sub Surface settlement

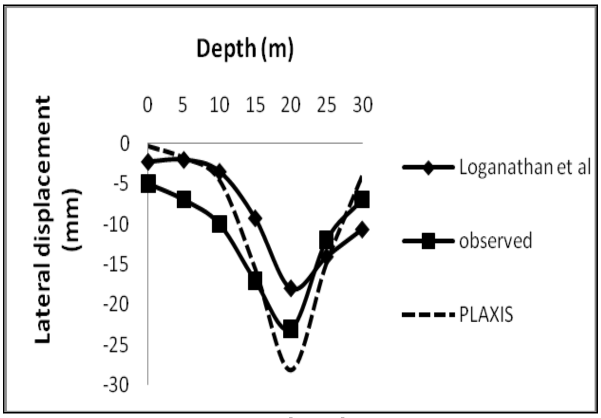

Fig-3 Lateral Displacement

3.1 PREDICTION OF GROUND MOVEMENTS FOR DIFFERENT CASES

It was decided to predict the ground movements for different conditions, by varying the following parameters and the soil type. The soil types considered are cohesive and cohesionless deposits of 35m thickness. Cohesive soil of three different consistencies and cohesionless soil of three different relative densities are considered. The tunnel parameters considered are placing depth and tunnel diameter. The different soil conditions and the input parameters are summarized in the table-1.

Table-1. Soil condition and soil parameters

Soil Type	**Condition**	**Deformation Modulus of soil, Es (MPa)**	**unit weight of soil, γ_d (kN/m^3)**	**Poisson's ratio, μ**	**Shear strength Parameter, C_u (kPa) or φ**
Cohesive Soil	Soft	3.5	15	0.4	50
	Medium	6.0	17	0.45	100
	Hard	14.5	19	0.5	200
Cohesionless Soil	Loose	28	16	0.3	30^0
	Medium	35	18	0.4	35^0
	Dense	70	20	0.45	40^0

The variation of maximum ground movements with respect to deformation modulus and tunnel dimensions are represented in charts. Charts shown in figure 4and 5 represents the maximum vertical settlement and maximum horizontal displacement for cohesionless soil. The chart shown in figure 6 and 7 represents the maximum vertical settlement and maximum horizontal displacement for cohesive soil.

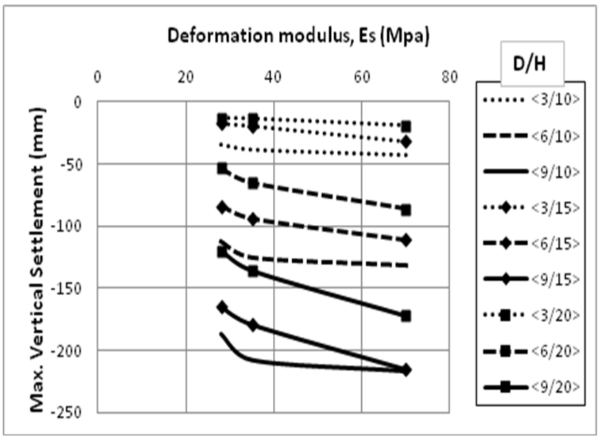

Fig-4 Maximum vertical settlement cohesionless soil

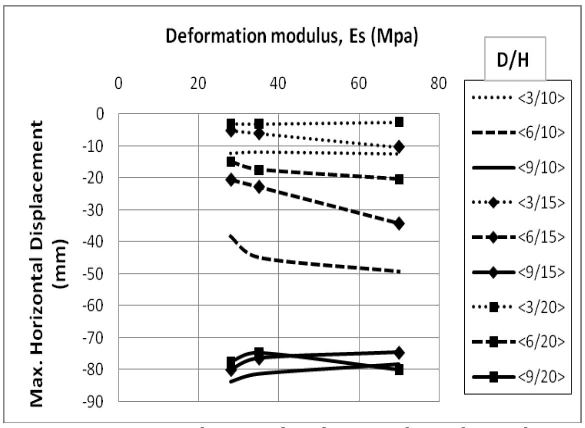

Fig-5 Maximum horizontal settlement cohesionless soil

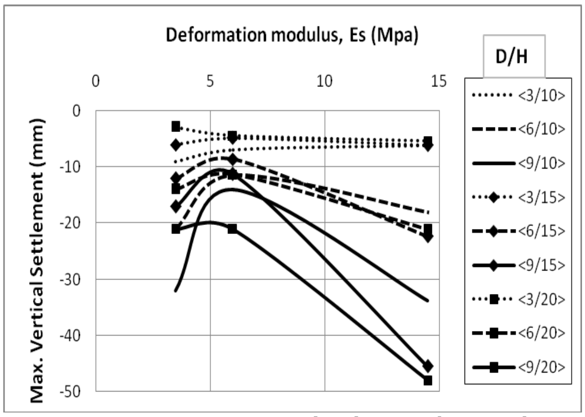

Fig-6 Maximum vertical settlement cohesive soil

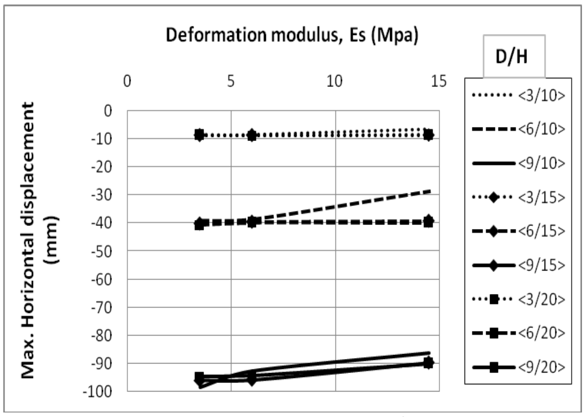

Fig-7 Maximum Lateral displacement of cohesive soil

These charts can be used for evaluation maximum ground movements for other conditions.

The general observations made from the table and figures are

i. Irrespective of the type of deposits, increase in the tunnel diameter increased the ground movements.
ii. Irrespective of the type of deposits, increase in placing depth of tunnel decreased the maximum ground movements.
iii. The ground movement for dense sand deposit is higher than loose and medium sand deposits.

The maximum ground movements observed for the different conditions of the analysis are also complied as charts and are shown in figure 4, 5, 6 and 7.

IV. VALIDATION OF PLAXIS ANALYSIS

A case study reported in the literature was selected to validate the Plaxis modeling and analysis. The present case study briefs the construction of a tunnel for the Angel Underground Station in London. The tunnel was driven between pile foundations supporting a seven-story building with a two-story basement. The tunnel axis line is 5.7 m from the centerline of the nearest piles. The tunnel was excavated using hand tools in two stages, the first a pilot tunnel of 4.5 m diameter and the second an enlargement of 8.25 m diameter. Measured ground loss ratio was 1.5% for the pilot tunnel and 0.5% for the tunnel enlargement (Mair 1993). The piles were driven through 28 m of London clay to the underlying Woolwich and Reading beds. Ground investigation data showed that the average undrained shear strength of London clay increased linearly from 50 kPa at the top to 220 kPa at the bottom. Inclinometers were installed at various locations within the ground to measure the lateral soil movements and within some of the piles to measure lateral pile deflections. Measured results were presented for a pile that had a diameter of 1.2 m and was located 5.7 m away from the tunnel axis line. At the pile location, the depth h of the tunnel axis level was approximately 15 m. The pile was treated as a single pile and the analysis was done. The undrained shear strength and deformation modulus used for the present analysis are cu = 135 kPa, soil Young's modulus Es = 54 MPa. The results are comparable and hence the analysis is valid. However the measured values are comparatively lower than the values that are predicted from software.

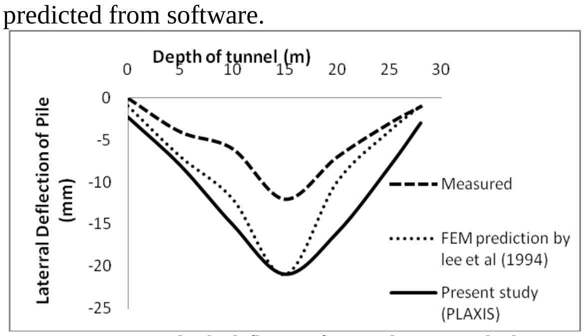

Fig-8 Lateral Pile deflection for case history studied

From figure 8 it is observed that the agreement between the computed and the measured profile is good. But the predicted maximum lateral deflection is higher than the measured maximum deflection.

V. RESPONSE OF PILE FOUNDATION FOR GROUND MOVEMENT

Response of pile foundation towards these predicted ground movement was determined by using software PLAXIS.

1. The Pile response determined using PLAXIS was compared with the case study reported in literature to validate the results of PLAXIS analysis.
2. Parametric studies were carried out to investigate the influences of various parameters on the pile responses. In these studies, the following parameters were varied:

- Tunnel radius, R
- Ground loss ratio, ε
- Angle of internal friction, φ

- Placing depth of tunnel, H
- Pile diameter, d
- Pile length, L_P.

A base case was considered for the analysis. The input parameters assumed for the analysis of base case are

•The tunnel is excavated through homogeneous sand with the friction angle 30°.
• Tunnel outer diameter, OD, is 6 m.
• Tunnel depth to centerline, H, is 20 m.
• Pile diameter, d, is 0.5 m.
• Pile length, Lp, is 15 m for short pile and Lp, is 25m for long pile.
• Young's modulus of the pile is 30 GPa.
• Ground losses are 1 & 5 percent.

Table-2 Different Parameters for analysis

Description	Parameters varied
Angle of internal friction, φ	30^0
	35^0
	40^0
Pile diameter, d in m	0.25m
	0.50m
	0.75m
	1.00m
	1.25m
Short Pile (L_p/H<1)	0.50
	0.75
	1.00

A parametric study was carried out by changing the base case parameters. The parameters varied with respect to base case for the analysis are shown in table-2 above. Based on the parametric studies, it was found that within the range of parameters examined, the various maximum pile responses can be approximated as follows:

Lateral response:

$$M_{max} = M_b.\ k^M_{\varphi}.\ k^M_d.\ k^M_{Lp/H} \quad \text{....... (1)}$$

$$\rho_{max} = \rho_b.\ k^{\rho}_{\varphi}.\ k^{\rho}_d.\ k^{\rho}_{Lp/H} \quad \text{....... (2)}$$

Axial response:

$$P_{max} = P_b.\ k^P_{\varphi}.\ k^P_d.\ k^P_{Lp/H} \quad \text{....... (3)}$$

$$v_{max} = v_b.\ kv_{\varphi}.\ kv_d.\ kv_{Lp/H} \quad \text{....... (4)}$$

Where:
M_{max} = maximum induced bending moment
M_b = maximum induced bending moment on the pile for base case
ρ_b = maximum lateral deflection of the pile for base case
ρ_{max} = maximum induced lateral deflection
P_{max} = maximum induced axial force
P_b = maximum axial force induced on the pile for base case
v_{max} = maximum induced pile head settlement
v_b = pile head settlement derived for base case.

Based on the parametric study, the following correction factors were derived for the various parameters that affect the magnitude of the tunneling-induced effects on piles:

• Angle of internal friction. Correction factors are k^M_{φ}, k^{ρ}_{φ}, k^P_{φ} and kv_{φ}
• Pile diameter. Correction factors are k^M_d, k^{ρ}_d, k^P_d, and kv_d
• Ratio of pile length to tunnel axis level. Correction factors are $k^M_{Lp/H}$, $k^{\rho}_{Lp/H}$, $k^P_{Lp/H}$, and $kv_{Lp/H}$.

The design chart was developed for the analysis of Short Pile responses in sandy soil. Compilation of the observed results was done and presented in the form of design charts.

5.1 DESIGN CHART FOR SHORT PILES (L_p/H<1)

The base case, a single pile and a tunnel configuration as shown in Figure 9, was analyzed to develop the design charts. Details of the base case are as follows:
• The tunnel is excavated through homogeneous sand with the friction angle 30°.
• Tunnel outer diameter, OD, is 6 m. Radius R=3m.
• Tunnel depth to centreline, H, is 20 m.
• Pile diameter, d, is 0.5 m.
• Pile length, L_p, is 15 m
• Young's modulus of the pile is 30 GPa.
• Ground losses are 1 & 5 percent.

The maximum pile responses for the short-pile case were established for the base case. Based on the observations made from the parametric study, it was decided to adopt normalized ground loss factor $\varepsilon_F = R^2\varepsilon_0$ to produce the design charts for the base case. Correction factors will be assessed based on the differences between the parameters for a specific project and those for the base case.

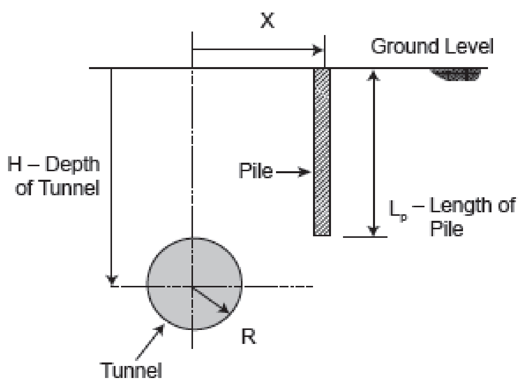

Fig-9 Short Pile (L_p/H<1)

Figure 10(a) to 10(d) shows the tunneling-induced effects on short piles for the base case with the ground loss factor $\varepsilon_{FB} = R^2\varepsilon_0 = 3^2$ x 1% = 0.09 and $\varepsilon_{FB} = R^2\varepsilon_0 = 5^2$ x 1% = 0.45

Figure 11(a) to 11(d) shows the variation of correction factors for the angle of internal friction of the soil varying from 30^0 to 40^0.

Figure 12(a) to 12(d) shows the variation of correction factors for the pile diameter varying from 0.25 m to 1.25 m.

Figure 13(a) to 13(d) shows the variation of the correction factors for the pile length/tunnel depth ratio varying from 0.5 to 1.0. This ratio has the most influence on the response of the pile.

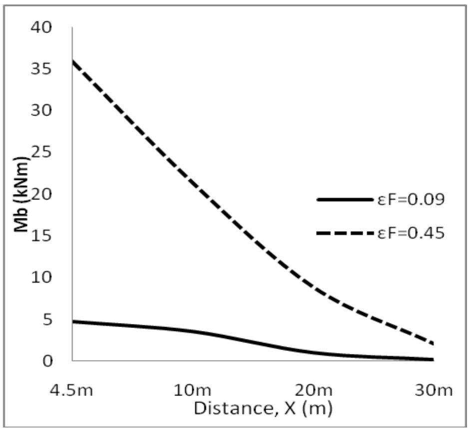

Fig-10(a) Maximum bending moment

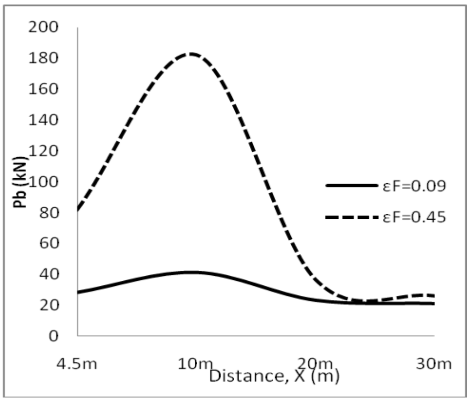

Fig-10(b) Maximum Axial Force

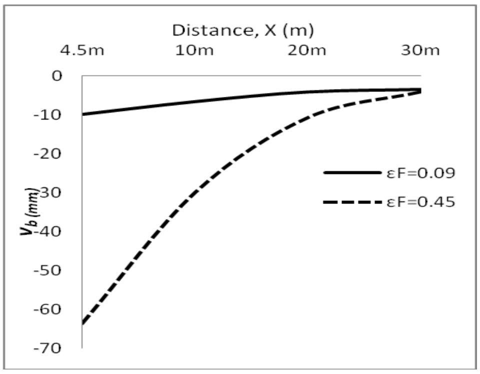

Fig-10(c) Maximum Pile head settlement

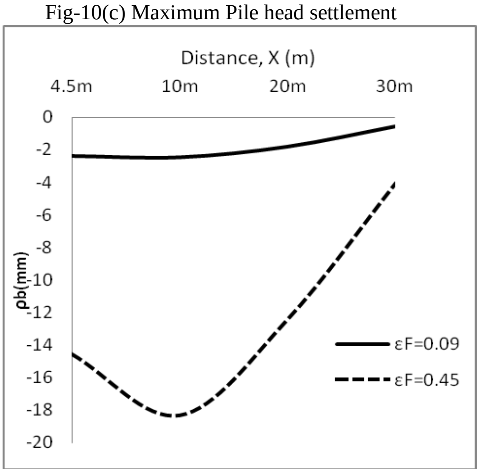

Fig-10(d)Maximum Lateral Deflection

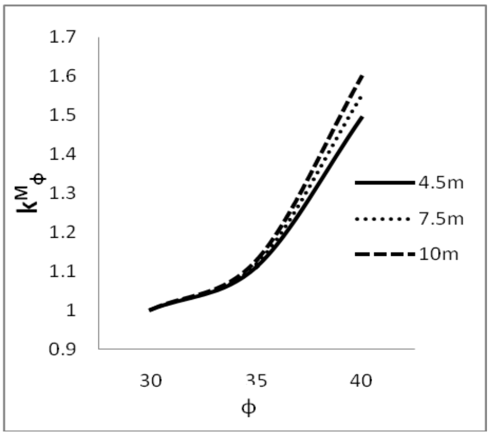

Fig-11(a) Max. B.M. Correction factor for(φ)

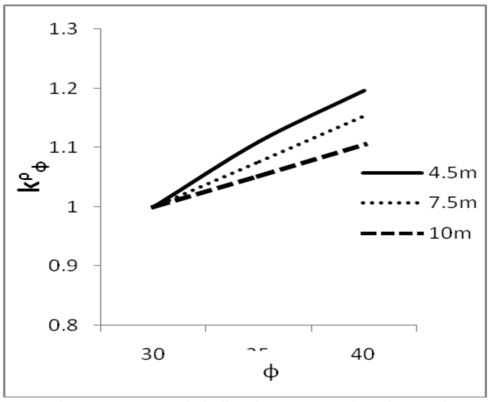

Fig-11(b) Max. Lateral deflection Correction factor for(φ)

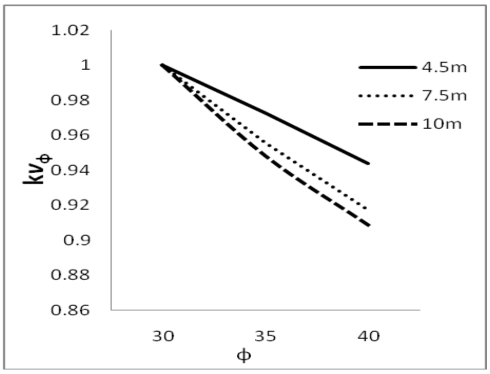

Fig-11(c) Max. Pile head Settlement Correction factor for(φ)

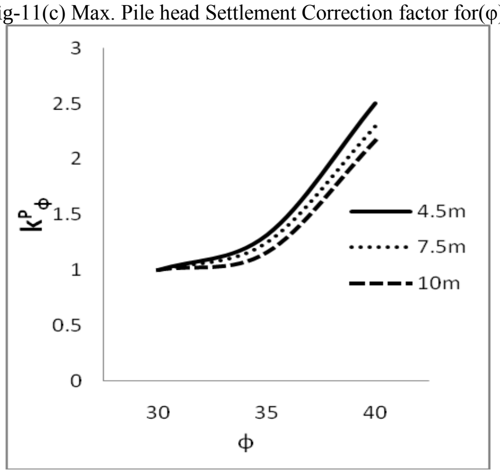

Fig-11(d) Max. Axial force Correction factor for(φ)

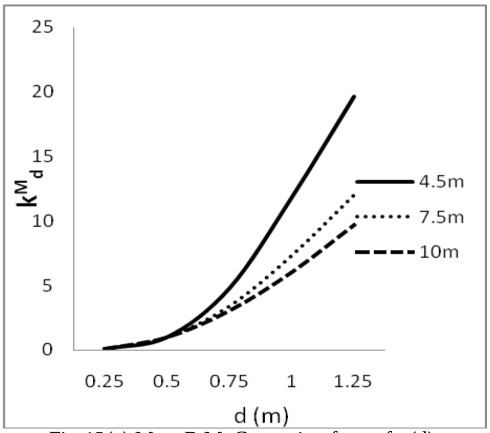

Fig-12(a) Max. B.M. Correction factor for(d)

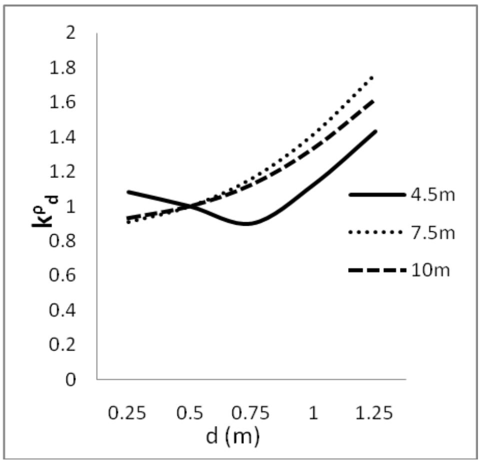

Fig-12(b)Max. Lateral deflection Correction factor for(d)

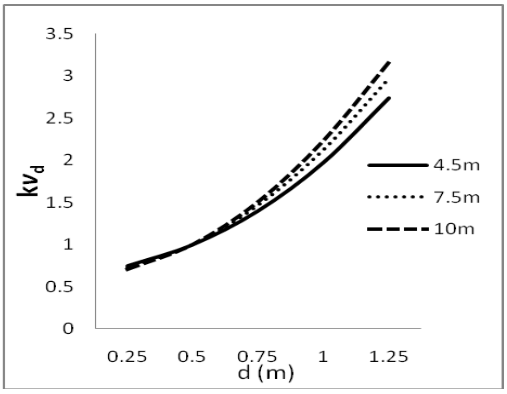

Fig-12(c) Max. Pile head Settlement Correction factor for(d)

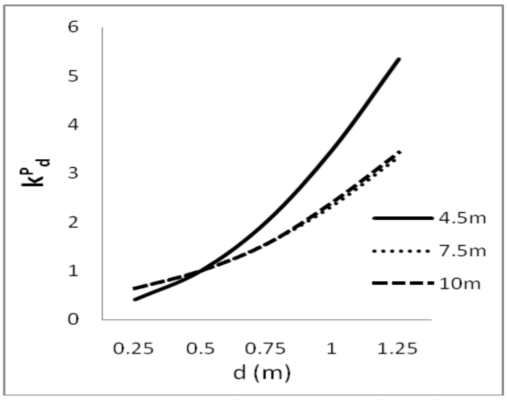

Fig-12(d) Max. Axial force Correction factor for(d)

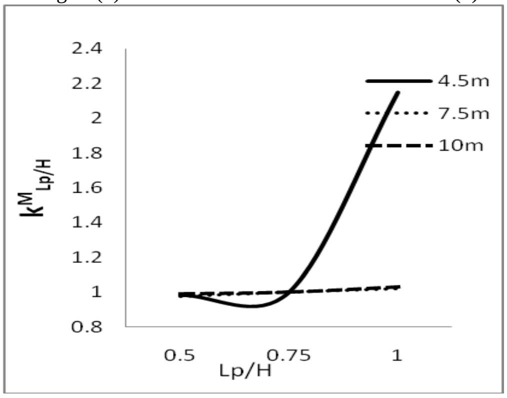

Fig-13(a) Max. B.M. Correction factor for (Lp/H)

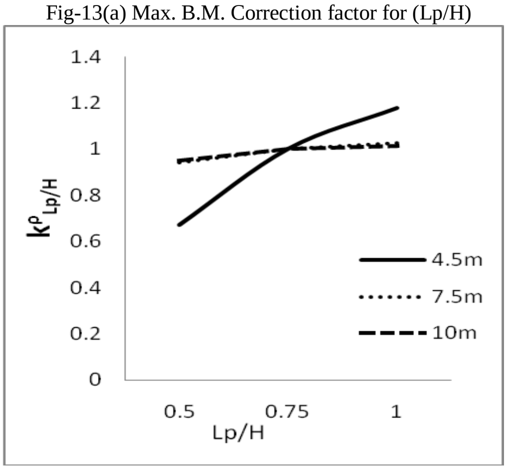

Fig-13(b) Max. Lateral deflection Correction factor for(Lp/H)

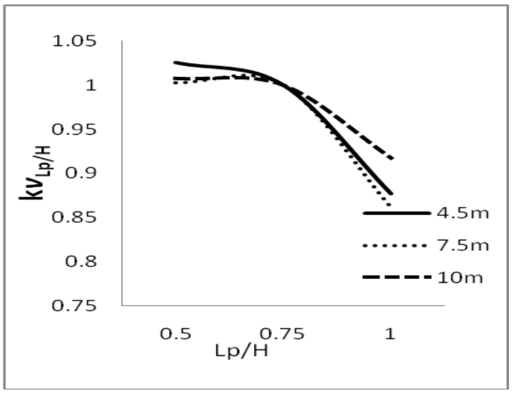

Fig-13(c) Max. Pile head Settlement Correction factor for(Lp/H)

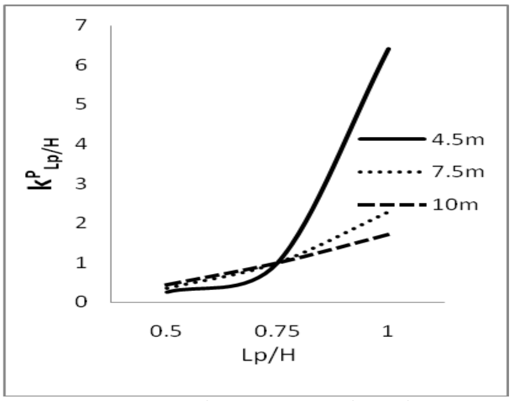

Fig-13(d) Max. Axial force Correction factor for(Lp/H)

VI. OBSERVATIONS

The observations made from the parametric studies in short pile is

Short Pile

i. Increase in the friction angle increases all the tunneling induced behavior such as bending moment, lateral displacement and axial force but pile head settlement reduces
ii. Increase in the pile diameter increases all the tunneling induced behavior
iii. Increase in the Pile length/ tunnel depth ratio causes decrease in pile head settlement.

VII. CONCLUSIONS

Here the ground movements were evaluated using different method and these ground movements were compared with the case studies reported in the literature. On comparing the ground movements estimated using different methods and with the measured results from the case studies PLAXIS 2D software is found to give upper bound estimate of ground movements than the other methods. Ground movements for different input parameter of soil and tunnel dimensions are also obtained using Plaxis software. Design charts for maximum ground movements were developed and are presented.

PLAXIS software is used to predict the responses of pile foundation for these ground movements. A case study was considered to validate the analysis of pile responses using PLAXIS. Parametric studies were carried out by changing the parameters of the base case. Design charts were developed for the tunneling induced behavior of short pile. Also the design charts for the correction factors were developed based on the parametric study for short pile. The design charts presented here can be used by the designers to predict the tunneling induced effects on short piles sand effectively.

REFERENCES

[1] Vermeer, P.A., and Bonnier, P.G. (1991). 'Pile settlements due to tunneling'. Proceedings of 10th European conference on Soil Mechanics and Foundation Engineering, Florence, Balkema, Vol-2, PP 869-872.
[2] Lee R G, Tumer A J, Whitworth L J (1994). 'Deformation caused by tunneling beneath piled structure'. Proceeding 13th International conference soil mechanics and foundation engineering, New Delhi, India. Vol-2, PP-873- 878
[3] Mroueh. H and Shahrour. I (2002). 'Three-dimensionalfinite element analysis of the interaction between tunneling and pile foundations'. International journal for numerical and analytical methods in Geomechanics, Vol- 26, PP 217-230.
[4] Cheng, C. Y., Dasari, G. R., Leung, C. F. & Chow, Y. K. (2002), 'Pile-Soil-tunnel interaction in some layered soil profiles'. The 15th KKCNN Symposium on Civil Engineering, Singapore PP 43-48.
[5] Jardine, R. J., St. John, H. D., Hight, D. W. & Potts, D. M (1991). 'Some practical applications of a non-linear ground model'. 10th European conference on Soil mechanics and foundation engineering. Florence, Vol-1, PP 223-228.
[6] HE Haijian, LIU Weining, XIANG Yanyong & WANG Ting (2003), 'Safety Analysis of the Influence of Metro Construction on Adjacent Bridge Piles', Chinese journal of Geotechnical Engineering, Vol-25(2), PP 2181-2186
[7] Matsumoto. T, Kitiyodom. P & Kawaguchi. K (2004). 'Three-dimensional analyses of piled raft foundations subjected to ground movements induced by tunnelling'. International journal of physical modelling in geotechnics, Vol-2, PP 20-36.
[8] Ong. C. W (2007) 'Performance of pile due to tunneling-induced soil movements', M Eng thesis, National University of Singapore.
[9] Loganathan N., and Poulos, H. G. (1998). 'Analytical prediction for tunneling induced ground movements in clays'. Journal of Geotechnical and Environmental Engineering, ASCE, Vol-124 (9), PP 846-856.
[10] Loganathan N (2011), 'An innovative method for assessing Tunneling-induced risks to adjacent structures'. Monograph,published by Parsons Brinckerhoff Inc. One Penn Plaza, New York 10119
[11] Chen, L. T., Poulos, H. G. and Loganathan, N. (1999), 'Pile Responses caused by tunneling', Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol-125(3), PP 207-215.
[12] Loganathan, N., Poulos, H. G. & Xu, K. J. (2001) 'Ground and Pile group responses due to tunneling'. Soil and foundations Vol-41(1); PP 57-67
[13] Surjadinata. J., Carter J. P., Hull T. S. and Poulos H. G. (2005), 'Analysis of Effects of Tunneling on Single Piles'. The University of Sydney, Sydney, Australia. Proceedings of 5th International symposium of TC28, PP 181-186.
[14] Lee C.J., Jun S. H. and Yoo N. J. (2007), 'The effect of tunneling on an adjacent single pile'. A case history, Proceedings of 4th International conference on Underground space of, ITA 2007, Department of civil Engineering, Kangwon National University, Korea. PP 527-532.
[15] Poulos H. G. (2011), 'Comparisons between measured and computed responses of piles adjacent to tunneling operations'. Geotechnique Letters. Published online at www.geotechniqueletters.com.
[16] Verruijt A, Booker JR (1996). 'Surface settlement due to deformation of a tunnel in an elastic half plane'. Geotechnique, Vol-46(4), PP 753-775.
[17] Sagaseta, C. (1987) 'Analysis of undrained soil deformation due to ground loss'. Geotechnique, Vol. 37, No. 3, pp. 301-320.
[18] Mair. R. J., Taylor R. N. and Bracegirdle. A (1993). 'Surface settlement profiles above tunnel in clays'. Geotechnique, Vol-43(2), PP 315-320.
[19] Peck, R.B. (1969). 'Deep excavations and tunneling in soft ground'. State of the art volume, Proceedings of 7th International Conference on Soil Mechanics and Foundation Engineering, Mexico City, pp. 225-290.
[20] 'Reilly MP, New BM (1982). 'Settlements above tunnels in United Kingdom– their magnitude and prediction'. Tunnelling'82, London, IMM. PP 173-181.