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RESEARCH ARTICLE

3D simulation of tunnel excavation in soft soil

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HIGHLIGHTS

- *The results showed the interest of such analysis.*
- *The good agreement acquired by this comparison has led to useful conclusions for the design of tunnel*
- *the study shows that we can use 2D calculations to approach the three-dimensional reality of tunnels at least in preliminary studies.*
- *This investigation can provide a reference for multi-tunnels design and construction.*

GRAPHICAL ABSTRACT

In tunnel engineering, soft ground tunneling has attracted the attention of tunnels engineers and researches. In this study, an analysis of the displacements and the tunnel face stability in soft ground (layered ground) using several calculation methods aimed at making confrontations are presented. Our purposes to approach 3D modelling in tunneling by a series of 2D computations using three procedures: The Lost Volume method (LVM), the Convergence Confinement method (CCM) and the face pressure method (P_F). A series of 2D and 3D numerical studies were carried out to estimate the settlements and longitudinal displacements and the tunnel face stability. Empirical approaches have also been used to make comparisons. The results showed the interest of such analysis. The comparison of the numerical results to those calculated with different methods shows good agreement.

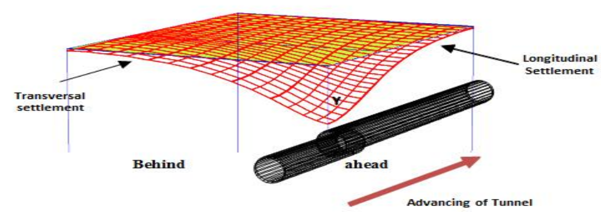

Figure A. Settlement trough obtained from 3D FE analysis

Keywords:

- Shield tunneling
- 3D, 2D simulation
- Settlement, Longitudinal displacement
- Face tunnel stability

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Aim of Article: *This paper reports the two and three dimensional numerical results of a study carried out to estimate the surface settlements, longitudinal displacements and face stability induced by the excavation of shallow tunnel in soft ground. Empirical approaches were also used to make comparisons. The aim of this study was to use several 2D calculation methods to account for the 3D effect in the tunneling.*

Theory and Methodology: *Tunnel excavation is a 3D problem. However, 3D numerical analysis often requires excessive computational resources (storage and time). Consequently, tunnel excavation is often simulated 2D. Various methods have been proposed to take account 3D effect of tunnel face to model tunnel construction. In this study, three methods are used to simulate tunneling in order to make comparisons: the Lost Volume method (LVM), the Convergence-Confinement method (CCM) and the face pressure method (P_f). We use Plaxis 2D and Plaxis 3D Tunnel software's for numerical calculation. Also, empirical and analytical approaches have been used to make comparisons using the popular methods of [1] for transversal displacement and [2] for longitudinal displacement.*

Findings and Results: *For predicting tunnel induced soil movement for shallow tunnel, we were highlights how 3D modelling the transverse settlement profile by comparing these results with 2D analyses using Plaxis finite elements software. The longitudinal settlement trough is also assessed with tunnel face stability. The results showed the interest of such analysis. The comparison of the 3D numerical results to those calculated with different methods 2D shows good agreement and led to useful conclusions for tunnel design.*

Conclusion: *in this paper, we have shown the interest of a 2D analysis using appropriate calculations confronted to 3D results, it turned out that the LVM and P_f methods provided results close to the actual excavation process. For the CCM method; the settlements are similar to those in 3D provided that the unsupported distance is reduced.*

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HIGHLIGHTS

- *The results showed the interest of such analysis. The results can be used to show the utility of using 2D sımulatıons instead of 3D for preliminary calculations.*
- *The good agreement acquired by this comparison has led to useful conclusions for the design of tunnel*
- *The study shows that we can use 2D calculations to approach the three-dimensional reality of tunnels at least in preliminary studies*
- *3D numerical analysis often requires excessive computational resources (storage and time). Consequently, tunnel excavation is often simulated 2D. Various methods have been proposed to take account 3D effect of tunnel face to model tunnel construction. The 3 methods used have shown their benefit.*

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ABSTRACT

In urban areas, tunneling can induce ground movements which disturb the soil and surrounding structures. In tunnel engineering, soft ground tunneling has attracted the attention of tunnels engineers and researches. Several calculation methods have been invested in order to evaluate these movements caused by the excavation of tunnels which the design requires a proper estimation of surface movements and face stability analysis, varying from simple empirical and analytical formulas to advance analyzes using the Finite Element Method. These analysis methods have significant effects on the estimation of the deformations because the analysis method must take into account the interaction between the tunnel and the ground; this turns out to be a purely 3D process which presents significant complexity and difficulties of understanding and a very high calculation time and cost, which is why the need has arisen to invest in 2D procedures which simple and useful for a first approximation and preliminary design. The main objective of this article is to analyze the excavation effect of a shallow tunnel excavated using tunnel boring machines (TBM) on soft layered ground (sand and clay) and to compare the results obtained from an empirical and analytical solutions with 2D and 3D finite elements numerical analyses. In this study, three calculation procedures were invested: Lost Volume Method, Convergence-Confinement Method, and Face Pressure Method. In parallel, a face stability analysis as well as failure mechanisms by face collapse were also obtained. The results showed the interest of such analysis. The comparison of the numerical results to those calculated with different methods shows good agreement.

Keywords: *Shield tunneling, Two and three dimensionnal Finite element analysis, Settlement, longitudinal displacement, tunnel face stability analysis*

I. INTRODUCTION

The increase in population requires urban space which becomes more limited, underground works have become an absolute solution to remedy this problem and to provide the required infrastructure. The process of tunneling is very complex and the tunnel excavation is a 3D Mechanism. A better understanding into these mechanisms that control the tunneling induced deformations could reduce costs and help avoid any problems [3]. However, 3D numerical analysis often

requires excessive computational resources (storage and time). In order to overcome this difficulty, engineers adopt simplified approaches using two-dimensional model, which is obviously a simplification of the real problem. Various methods have been proposed to take into account the 3D effect of the working face to model the construction of the tunnel in 2D such as: the ground volume loss method (LVM), the Convergence-Confinement method (CCM) and the face pressure (P_f).
Several authors have carried out research to account for three-dimensional aspects in two-dimensional models [4-5-6-7-8-9-10]. These 2D models frequently lead to satisfactory displacement values with respect to measurements and to an estimate of the redistribution of stress [11].

Mroueh and Shahrour proposed a simplified 3D numerical model for the prediction of ground movements induced during the construction of a tunnel using TBM (Tunnel Boring Machine) based on the generalization of the Convergence-Confinement method (CCM) only [6]. Vitali and others show that 3D model agrees a more accurate analysis of the soil's construction effects and the repercussions of some key parameters such as the injection grout and chamber pressures [12]. In the study of [13], the authors focuses on the three-dimensional cross excavation problem of two tunnels, the numerical analysis method is used to study the effect of multi-tunnel excavation on the settlement of the ground surface. A series of three-dimensional finite element models were constructed to consider the intersection of two tunnels with different relative positions and different spacing. In their study, the 2D simulation is extended to 3D simulation for a more comprehensive understanding of the ground deformation affected by twin tunnel excavation. These models take into account only the ground volume loss method (LVM). [14] investigate the surface subsidence due to tunneling in 3D, the simultaneous impact of depth and diameter of the tunnel in both saturated and dry conditions have been investigated also using a FLAC3D Finite Difference program. Results showed that depth and diameter induce a significant effect on the ground surface displacement values. As face pressure increases (P_f), the effect of tunnel depth and diameter on surface and crown displacements decreases.
To date, the majority of research work done to predict movement caused by tunneling uses one method to take account the 3D effect into 2D calculation. In our study, the main objective is to develop a better understanding of the behavior of tunneling in ground using several methods at the same time. The main objectives of this paper are three-fold: first, to provide a 2D dimensional numerical analysis to model the tunneling process of the TBM (tunnel boring machine) in three methods: 1. the ground loss volume (LVM) method, 2. the convergence confinement method (CCM) and 3 face pressure method (P_f method). Second, to simulate the 3D numerical analysis for a proper prediction of surface movement. To investigate its development, Plaxis 3D tunnel FE program is used; and third, to analyze the stability of the face. In addition, empirical approaches have been used to make comparisons using the popular methods of [1] for transversal displacement and [2] for longitudinal displacement. The empirical results found have enriched the study. Comparisons are presented, with the results showed the usefulness of one method over the other.

II. THEORY AND METHODOLOGY

There are mainly two settlement prediction approaches: (i) empirical, based on empirical formulas derived from past observations, (ii) numerical analysis such as finite element approach, which is the most popular method. In this study, both methods are employed to predict the surface settlement above the tunnels.
We use empirical approaches using the popular methods of [1] for transversal displacement and [2] for longitudinal displacement. And Plaxis 2D and Plaxis 3D Tunnel software's for numerical calculation.

II.1 Empirical prediction for tunneling induced ground

The empirical methods are almost simple and useful. However, their use is limited for design purposes. Empirical methods aim at estimating the extent of the movements starting from a relatively thus reduced number of data they make it possible to obtain preliminary results which it is necessary, however, to use them with a great precaution. In practice, these methods should be more or less guided by the analytical approaches if they exist or by numerical calculations and then to fix them on the experimental curves [15].
Tunneling will generally induce both *transversal* and *longitudinal* settlements of ground movements.

II.1.1 Transverse behavior Tunnel induced ground

The settlements which result from various excavation phases generally has been found that the shape of the

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surface settlement troughs developing during tunnel construction is reasonably well represented by a Gaussian distribution described for the first time by [1] as shown in Figure 1, the settlement S as:

$$Sv(x) = S_{max}\exp(\frac{-x^2}{2i^2}) \quad (1)$$

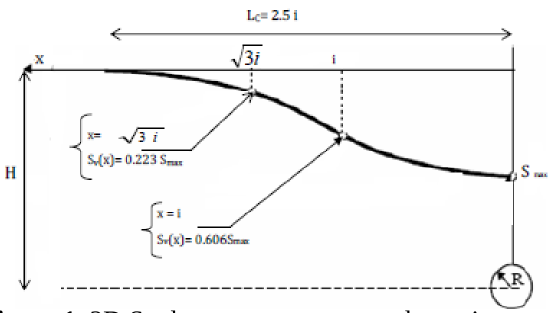

Figure 1. 2D Settlement parameters and notation.

where S_{max} is the maximum settlement, which occurs above the tunnel centre line; The width of settlement profile is defined by the important parameter i, which is the distance from the tunnel centre line to the point of inflexion of the trough (shown in Fig. 2);

The maximum settlement is calculated using the [16] formula for the case of a circular tunnel with diameter D:

$$S_{max} = \frac{0{,}313\ V_l}{i} D^2 \quad (2)$$

For practical purposes, it is often reasonable to assume that simple approximate ratio is given by [10] delimiting the inflection point i: i=KH

With: H: tunnel depth, K is usually in the range from 0.4 to 0.5 for the cohesive soils and 0.25 to 0.35 for the cohesiveness soils [8].

The settlements caused by tunneling are often characterized by the term volume loss (V_L), expressed as a percentage of the notional excavated volume of the tunnel.

Figure 2 shows the influence of volume loss on the amplitude of settlement. The settlements increase with increase of loss volume.

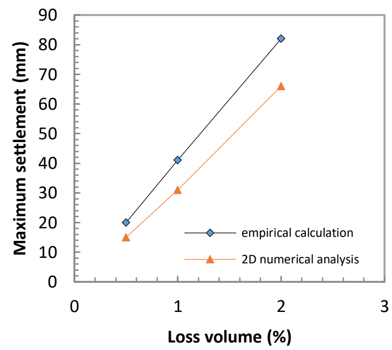

Figure 2. Influence of the loss volume (V_L) on the maximum surface settlement

II.1.2 Longitudinal behavior

The [2] empirical formula is used to assess surface settlement in the longitudinal direction:

$$S_v(x) = S_{max}.\frac{1}{i\sqrt{2\Pi}.}\int_{-\infty}^{x} e^{-\frac{x^2}{2i^2}} \quad (3)$$

Where x : is the distance to the face of the tunnel in the longitudinal direction of settlement.

[2] indicate that the values of minima settlement and maxima are reached respectively with x=+∝ (ahead of the face) and at x=-∝ (behind the face). They find that settlement ahead of the face is reduced significantly (Figure 3).

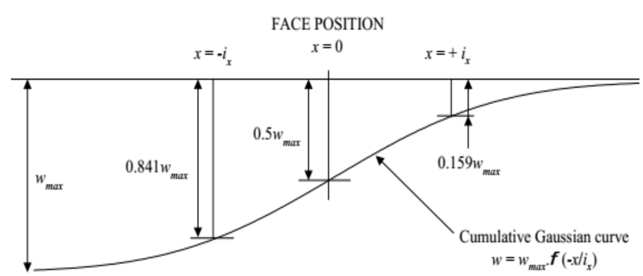

Figure. 3. Empirical longitudinal settlement trough [8].

Both [1] and [2] formulas were adopted in this study for empirical calculation in order to estimate surface settlements in the transverse and longitudinal direction. It is about a trough of longitudinal settlement which ensures the model quoted in the literature, where displacements far ahead of the face are practically negligible and this at a distance from the order of a 1,5 Diameter approximately. At the face, these settlements are equal to 50% of maximum settlement.

II.2 Numerical modeling

II.2.1 Two dimensional analyses

Tunnel excavation is a three-dimensional problem. However, 3D numerical analysis often requires excessive computational resources (storage and time). Consequently, tunnel excavation is often simulated 2D.
Various methods have been proposed to take account 3D effect of tunnel face to model tunnel construction. In this paper, three methods are used to simulate tunneling in order to make comparisons: the loss Volume method (LVM), the Convergence-Confinement method (CCM) and the face pressure method (P_f).

1. The Convergence-Confinement Method (CCM)

This method which is also referred to as the λ method was introduced by [17]. The parameter λ describes the proportion of unloading before the lining is installed. For $0 < \lambda < 1$ the remaining radial stress on the lining is $\sigma_r = (1-\lambda)\ \sigma_0$ where σ_0 is the initial stress in the radial direction.
Using the following formula [18] :

$$\lambda(x)= \alpha+ (1-\alpha) [1-(m_0R/ (m_0R+x)2] \quad (4)$$

With: α and m_0 are two constants (Taken respectively 0.25 and 0.75) and R: radius of excavation.
The three-dimensional character of the tunneling process is introduced in this two-dimensional representation by means of the convergence-confinement method [19], which makes it possible to simulate the advance of the facet by means of a dimensionless parameter λ [11].

2. The face pressure method (P_F)

A face stability analysis relates directly to the face pressure applied to the ground; the correct assessment of this pressure to avoid the instability of tunnel face has been the crucial obligation of various researchers who have proposed analytical approaches to determine this pressure.
Most of these approaches are based on the limit equilibrium method (called LEM) introduced by [20-21-22-23-24-25] or of limit analysis method (LAM) proposed by researchers such as [26-27-28-29].

Table 1

Analytical evaluation of the face pressure (LEM and LAM)

Authors	Formula	LEM	LAM
Broms & Bennermark (1967)	$P_F = q_s+\gamma H-Nc_u$	188kPa	-
Krause (1987)	$P_F=(D\gamma/3-\Pi c/2)/\tan\phi$	90 kPa	-
Davis and al.(1980)	$N=2+2\ln(c/R+1)$	-	179 kPa
Atkinson & Mair (1981)	$P_F = q_s+\gamma H-(Nc_u/ Fs)$	-	195kPa

Where: γ= soil unit weight, c_u=undrained shear strength of the ground, q_s=surcharge, H: Depth, N: stability ratio, F_s: security coefficient, D= tunnel diameter, c: cohesion, ϕ: friction angle.
We use P_F = 90 kPa calculated using the [21] formula.
Only the method of Krause appears to provide a face pressure giving of the results being used to maintain the stability of ground.

3. Loss Volume Method (LVM)

The loss volume (or contraction) method, implemented in Plaxis, is a process stimulated by [30], where ground loss is simulated by tunnel contraction. This method consists of annulling out the foundation elements inside the tunnel and letting the rest of the foundation deform until the volume occupied by the tunnel is reduced in accordance with a fixed rate. The loss volume is simulated by applying a contraction to the tunnel lining. A contraction rate of 0.5% was adopted following parametric studies (See figure 2).

III. APPLICATION TO A MODEL STUDY

The case considered for this study is schematized in Figure 4. It is concerning a shallow circular tunnel excavated with the TBM (Tunnel Boring Machine). The tunnel which is 8.5m. The tunnel axis lies 11.0 m below the ground surface. The model is 20.0 m wide, it extends 25.0 m in the Z-direction and it is 20.0 m deep. With these dimensions, the model is sufficiently large to allow for any possible collapse mechanism to develop and to avoid any influence from the model boundaries. The subsoil consists of three layers. The upper sand layer is 2.0 m deep and extends from the ground surface. Below the upper sand layer there is a clay layer of 12.0 m thickness and this layer is underlain by a stiff sand layer that extends to a large depth. Soil model is modeled using the Mohr-Coulomb criterion,
Only one symmetric half is included due to symmetry. The characteristics of the material are summarized in table 2.
The tunnel lining was modelled with an elastic model where flexural rigidity: EI = 143 MNm^2 and a normal rigidity: EA=14 GN. And lining thickness e=0,35m.
The TBM and the soil are modelled by means of an interface. The interface allows for the specification of a reduced friction compared to the friction in the soil.

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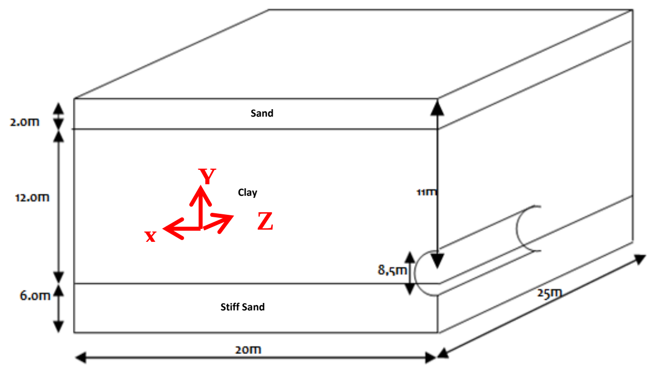

Figure 4. FE mesh for tunnel excavation

Table 2.
Material properties of soils

Parameter	Name	Sand 1	Clay	Sand 2	unit
Materiel Model	Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	-
soil Weight	γ_h	20.0	18.0	20.0	kN/m^3
Young's Modulus	E	1.3 .10^4	1.0.10^4	7.5.10^{+4}	kN/m^2
Poisson's ratio	υ	0.3	0.35	0.3	-
Friction angle	φ	31.0	25.0	31.0	°

IV. Two dimensional FE Analysis

Tunnel excavation is a three-dimensional problem [31-32]. Fully three dimensional (3D) numerical analysis, however, often requires excessive computational resources (both storage and time). Therefore, tunnel excavation is often modelled two dimensionally (2D).
In tunnel engineering, numerical analysis by the finite element method (FEM) is widely utilized to understand the stresses and deformations around the tunnel because it can deduce indications clearly.

IV.1 Transverse behavior

For this part of study, all numerical analyses were carried out using Plaxis 2D finite element programs. In plane strain, the soil was modeled by 15-nodes elements with 7860 nodes and 945 elements.
Figure 5 shows 2D FE mesh and boundaries conditions for model. The horizontal and vertical displacements are assumed to be zero at the level of the substratum and the horizontal displacements are blocked on the lateral sides.

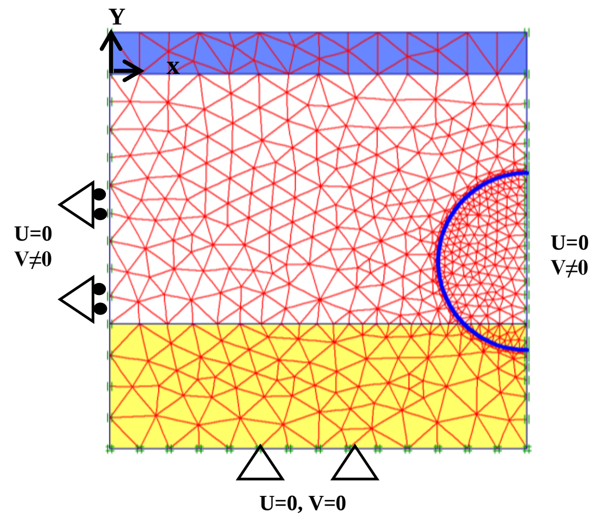

Figure.5 2D Finite Elements mesh

Figure 6 shows the development of transverse settlement with tunnel progress.
It's showing the comparison between the results obtained for the 3 methods of calculation 2D with that resulting from the method of [1] and calculation 3D. In the transverse direction, the surface settlement profile obtained is fairly consistent with the experimental observations. each method reproduces a different maximum settlement value but close to that of the three-dimensional settlement trough only the two methods known as face Pressure (P_f) and Contraction (LVM) make it possible to describe the 3D curve in a very satisfactory way the 2D numerical approach called Convergence confinement with a confinement of 60% predicts the widths and inflection points of troughs more or less close to the 3D troughs. It is seen clearly that the profiles are connected perfectly with the normal curves for the three methods.

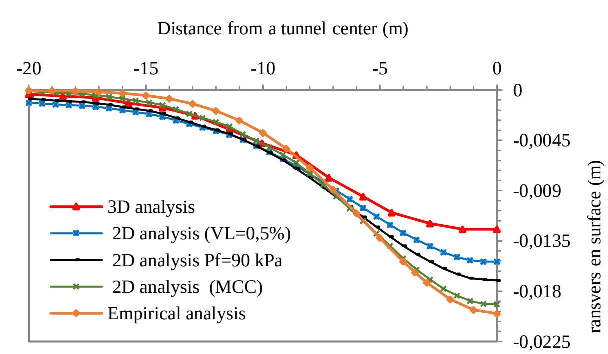

Figure.6 Transverse surface settlement troughs

IV.2 Longitudinal behavior

Figure 7 represented longitudinal displacements surfaces, it is showing the similarity of the two curves for maximum settlement, both troughs corroborate the model quoted in the literature, the only difference resides in the value of maximum settlement (S_{max}). The maximum settlement is about 12mm in the numerical curve and that carried out S_{max}=20mm for empirical calculation. It should in parallel be announced that settlement at the face is equal to 50% of maximum settlement.

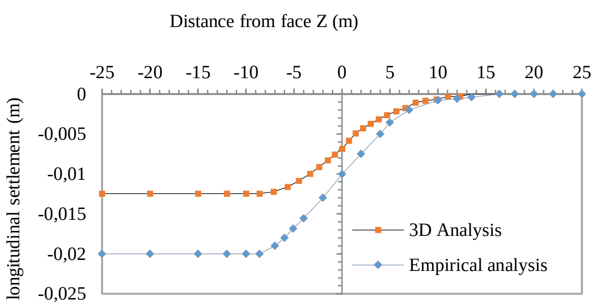

Figure.7 Longitudinal surface settlement troughs

V. 3D DIMENSIONAL FE ANALYSIS

The prediction for transverse settlement profiles can be improved by applying fully 3D FE analysis.
Numerical analyses were carried out using Plaxis 3D tunnel finite element program. 3D parallel strain were used, the soil was modeled by 15-nodes wedge elements with 3447 nodes and 10596 elements. **Figure 8** shows 3D mesh and boundaries conditions for model.

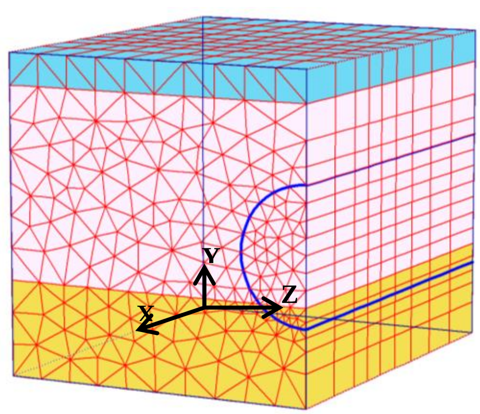

Figure. 8 3D FE mesh for tunnel excavation

V.1 Transverse Analysis

The analysis of the 3D results constitutes a difficulty because of the quantity significant of information to be treated. An analysis of the results starting from cuts in 2D already requires at this stage a considerable effort. If it is considered that volume 3D is formed by an infinity of plans 2D, which can contain significant information, and then we can easily imagine the quantity of data to be analysed. We thus had only some results selected among the thousands available.
Figure 9 shows a vertical displacement at the face of the tunnel (It's about of approximately 12mm) which reaches its maximum on crown and is propagated on the surface in transversal and longitudinal directions by reducing amplitude and while spreading themselves in ahead of tunnel.
Thus, we can conclude, in parallel, that the face pressure applied at the origin of calculations is sufficient to maintain the stability of the face.

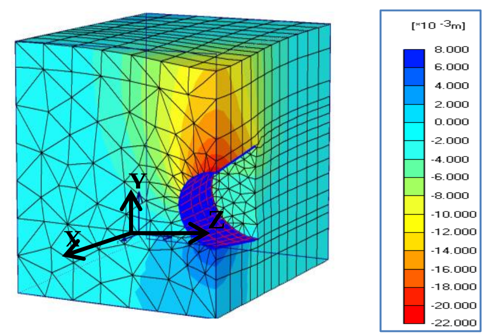

Figure. 9. Vertical displacement

V.2 Face stability Analysis

Soft ground tunnelling in urban areas is more frequently being performed using the shield method. Due to its great influence on both ground settlement and construction safety, face stability is one of the most critical problems in shield tunneling.
In this research, a series of calculation were conducted using different formula to determine the required collapse pressure of a tunnel face during tunneling in our layered soils (See table 1).

In this part, we have analyses the face tunnel stability of. In tunneling, the face needs to be continuously supported with a liquid pressure, air, or with a pressure of ground. In our case, the pressure applied is in liquid form (bentonite). This pressure is limited between two values

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(a minimum and a maximum). A too low pressure can lead to the face collapse (active state); and too high pressure can take along to a blow-out and rising on the surface (passive state) [33].

Stability can be defined by means of a safety factor; which is implemented in Plaxis 3D tunnel program.

Figure 10 shows the mechanism of failure of model, note that our first model is regarded as a heterogeneous ground and this nature of ground is not studied in the literature and obtaining the mechanism of failure around the face was difficult.

We notice a mechanism of failure in the form of chimney; inward a ground surface forming a crater of the order of approximately one diameter; what corresponds, more, with the mechanism of failure quoted in the literature.

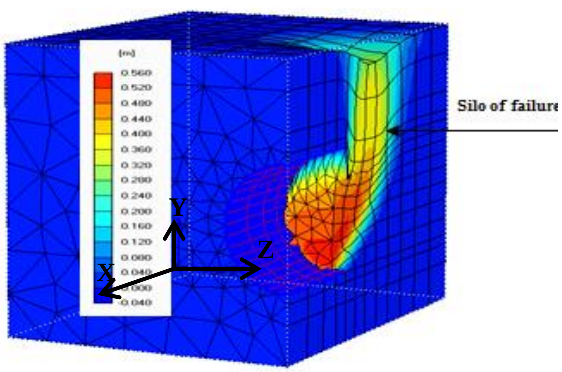

Figure. 10 Mechanism of failure of Tunnel

In parallel, our analyses were extent with calculations of extrusion to the face for other values of face pressure lower than that which is enough to maintain stability (P_F=90kPa). Probably, some one of these values (P_F=70kPa, P_F=80kPa) gave the same results of deformations; nevertheless for others like P_F=50kPa, P_F=40kPa, P_F=30kPa; we found a failure.

These observations lead to a strong result for the practice: the increase in the face pressure has, certainly tendency to limit settlement of surface ahead of shield, but results also in to accelerate settlements of surface behind the face. The maximum face pressure to use must thus be quite selected carefully.

Figure 11 exposes the results of surface longitudinal settlement while varying face pressures by pushing the mechanism to the failure. Settlements observed can be directly connected to the imposed face pressure value. This good correspondence confirms the interest which the estimate of this parameter carries which could bring into play all the stability.

Indeed, when this face pressure is higher than the earth pressures (σ), movements of repression are observed whose amplitude is increasing with the face pressure.

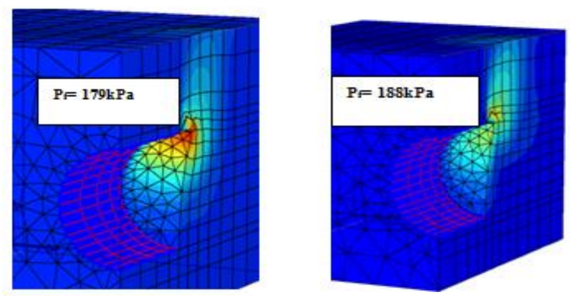

Figure. 11. Failure mechanism for various face pressure.

VI. CONCLUSION

This paper reports 2D and 3D numerical results of a study carried out to estimate the surface transverse and longitudinal settlements and face stability induced by the excavation of shallow tunnel in soft ground. Empirical approaches were also used to make comparisons. The aim of this study was to use several 2D calculation methods to account for the 3D effect in the tunneling.

Tunnel excavation is a 3D problem. However, 3D numerical analysis often requires excessive computational resources (storage and time). Consequently, tunnel excavation is often simulated 2D. A suite of FE analyses was performed to investigate the influence of 3D effects on the tunnel induced surface settlement trough.

Various methods have been proposed to take account 3D effect of tunnel face to model tunnel construction. Three methods are used to simulate tunneling in order to make comparisons: the Lost Volume method (LVM), the Convergence-Confinement method (CCM) and the face pressure method (Pf). We use Plaxis 2D and Plaxis 3D Tunnel software's for numerical calculation and empirical approaches have been used to make comparisons using the popular methods of [1] for transversal displacement and [2] for longitudinal displacement. We showed the utility of empirical calculations like first approximation at the preliminary studies. However, it is necessary, to pay attention as for the choices of the value of the loss volume (V_L) which would have, a priori, being equalizes to 0,5% ; a value which enabled us to arrive at a very good agreement with calculations 3D ; the choice of this parameter proved very influencing that it is for an empirical or even numerical study.

The soil response to excavation is significantly affected by the presence of the face. A face stability analysis relates directly to the face pressure applied to the ground; the correct assessment of this pressure to avoid the instability of tunnel face has been the crucial obligation of various researchers who have proposed analytical approaches to determine this pressure.

In our study, we notice a mechanism of failure in the form of chimney; inward ground surface forming a bowl of the order of approximately one diameter.

Information on the failure mechanisms by face collapse could be obtained during this analysis. The failure mechanism found was found to be very close to that observed. A too low pressure can lead to the face collapse (active state); and too high pressure can take along to a blow-out and rising on the surface.

Also, we found the results of surface longitudinal settlement while varying face pressures by pushing the mechanism to the failure. Settlements observed can be directly connected to the imposed face pressure value. This good correspondence confirms the interest which the estimate of this parameter carries which could bring into play all the stability. Indeed, when this face pressure is higher than the earth pressures (σ), movements of repression are observed whose amplitude is increasing with the value of the face pressure.

CONFLICTS OF INTEREST

There are not conflict of interest between the authors and their respective institutions.

RESEARCH AND PUBLICATION ETHICS

In the studies carried out within the scope of this paper, the rules of research and publication ethics were followed.

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REFERENCES

[1] Peck R. B. Peck (1969). Deep excavations and tunnelling in soft ground.

[2] Attewell, P. B. (1978). Ground movements caused by tunnelling in soil. Pages 812-948 of: Large ground movements and structures. Pentech Press, London.

[3] Franzius J. N. (2003). Behaviour of buildings due to tunnel induced subsidence. Thesis (PhD). London: Imperial College, University of London.

[4] Ozkaya, U., Melgani, F., Bejiga, M. B., Seyfi, L., and Donelli, M. (2020). GPR B scan image analysis with deep learning methods. Measurement, 165, 107770.

[5] Dias, D., and Janin, J.P., and Soubra, A.H., and Kastner, R. (2008), “Three-dimensional face stability analysis of circular tunnels by numerical simulations”, The Challenge of Sustainability in the Geoenvironment 'GeoCongress 2008', New Orleans, USA.

[6] Mroueh, H., and Shahrour, I. 2008. A simplified 3D model for tunnel construction using tunnel boring machines. Tunnelling and Underground Space Technology 23 (2008) 38–45.

[7] Demagh, R., Emeriault F. et Kastner R. (2008). Modélisation 3D du creusement de tunnel par tunnelier à front pressurisé dans les sols surconsolidés. Journées Nationales de Géotechnique et de Géologie de l’Ingénieur (JNGG’08) Nantes, 18-20 juin 2008, 305-312.

[8] Bloodworth, A. G. (2002). Three-dimensional analysis of tunnelling effects on structures to develop design methods: Thèse de doctorat : Université d’Oxford, Grande Bretagne.

[9] Kasper, T., and Meschke, G. (2004). A 3D finite element simulation model for TBM tunneling in soft ground. International Journal for Numerical and Analytical Methods in Geomechanics, vol. 28, pp. 1441-1460

[10] Liu, G. (1997). Numerical modelling of damage to masonry buildings to tunnelling. Thèse de doctorat : Université d’Oxford. Grande Bretagne.

[11] Nguyen, P. G. (2003). Modélisation numériques des soutènements d’excavation. Thèse de doctorat. École nationale des ponts et chaussées.

[12] Vitali OP, Celestino TB and Bobet A 2018 3D finite element modelling optimization for deep tunnels with material nonlinearity. Underground Space. 3(2) 125-139.

[13] Jin Y. F. Zhu B. Q., Yin Z. Y., Zhang D. M. (2019) Three-dimensional numerical analysis of the interaction of two crossing tunnels in soft clay. Underground Space 4 (2019) 310–327.

[14] Ramsheh F. A., Rashiddel A. , Dias D. (2021). 3D numerical simulations of tunneling induced soil deformations Phys.: Conf. Ser. 1973 012207.

[15] AFTES (1995). Tassements lies au creusement des ouvrages en souterrain. Revue Tunnels et Ouvrages Souterrains, vol. 132, pp. 373-395.

[16] Greenwood, J.D. (2003). Three-dimensional analysis of surface settlement in soft ground tunnelling, Master of

JOURNAL OF SCIENCE, TECHNOLOGY AND ENGINEERING RESEARCH
Bilim, Teknoloji ve Mühendislik Araştırmaları Dergisi, (2023) - 4(1): 67-77
ISSN : 2717-8404 *https://dergipark.org.tr/en/pub/jster*

Engineering in Civil and Environmental Engineering, University of Minnesota, USA, 90p.

[17] Panet M., Guenot A. (1982), Analysis of convergence behind the face of a tunnel. Proc. Int. Symp. : Tunnelling 82, Brighton.

[18] Martin, F. (2012) Mécanique des Roches et Travaux Souterrains. Huitième édition Janvier 2012

[19] Panet M. (1995). Le calcul des tunnels par la méthode convergence-confinement, Presses de l'ENPC.

[20] Broms B.B., Bennermark H. (1967), Stability of clay at vertical openings. Journal of the Soil Mechanics and Foundations Division, ASCE, SM1 January 1967, pp. 71-94.

[21] Krause, T. (1987). Schildvortrieb mit fltissigkeits- und erdgesttitzter Ortsbrust. Dissertation TU Braunschweig.(in German).

[22] Jancsecz, S. and W. Steiner (1994). Face support for large Mix- Shield in heterogeneous ground conditions. Tunneling 94. London.

[23] Anagnostou G., Kovári K. (1996). Face Stability Conditions with Earth Pressure Balanced Shields. Tunnelling and Underground Space Technology, 11, No. 2, 165-173.

[24] Broere, W., 2001. Tunnel Face Stability and New CPT Applications, Dissertation, TU Delft 2001.

[25] Carranza-Torres, C. (2004). " Computation of factor of Safety for Shallow Tunnels using Caquot's Lower Bound Solution. " In Publication.

[26] Atkinson J. H., and Potts D. M. (1977). Stability of a shallow circular tunnel in cohesionless soil. Volume 27 Issue 2, June 1977, pp. 203-215. https://doi.org/10.1680/geot.1977.27.2.203

[27] Davis E.H., Gunn M.J., Mair R.J., Seneviratne H.N. (1980), The stability of shallow tunnels and underground openings in cohesive material. Geotechnique, 30. n° 4, pp. 397-416.

[28] Leca e dorm Leca E., Dormieux L. (1990). Upper and lower bound solutions for the face stability of shallow circular tunnels in frictional material. Géotechnique, Vol. 40, N° 4, pp. 581-606.

[29] Javad, M., and Shahriar, K., and Moarefvand, P. (2011). Tunnel Face Stability Analysis in Soft Ground in Urban Tunneling by EPB Shield. (Case Study: 7 th Line in Tehran Metro). Australian Journal of Basic and Applied Sciences, 5(11): 589-601, 2011 ISSN 1991-8178.

[30] Vermeer PA and Brinkgreve R (1993) PLAXIS Version 5 Manual. Balkema, Rotterdam, the Netherlands.

[31] Swoboda, G. 1979. Finite element analysis of the New Austrian Tunnelling Method (NATM). Page 581 of: Proc. 3rd Int. Conf. Num. Meth. Geomech., Aachen, vol. 2.

[32] Gens, A. 1995. General report: Prediction, performance and design. Pages 1233 { 1247 of: Int. Symp. on pre-failure deformation charact. of geomaterials. Balkema, Rotterdam.

[33] Anagnostou G. (2002). Urban tunneling in water bearing ground–Common problems and soil mechanical analysis methods. Proc. 2nd Int. Conference on Soil Structure Interaction in Urban Civil. Engineering.

[34] Anagnostou, G. and Kovári, K. (1996). Face Stability Conditions with Earth Pressure Balanced Shields. Tunnelling and Underground Space Technology, 11, No. 2, 165-173.

[35] Anagnostou G. Kovári K. (1997). Face stabilization in closed shield tunneling. Rapid Excavation and Tunnel Construction, Las Vegas.

[36] Atahan C. (1995). Modélisation numérique du creusement d'un tunnel à l'aide d'un bouclier à pression de boue. Thèse de doctorat : École Nationale des ponts et chaussées.

[37] Berredane, A., and Allal, M. A. and El Houari, N. (2019) "Interaction between two tunnels constructed at low depths : Case of a frictional and coherent soil". The First International Conference on Materials, Environment, Mechanical and Industrial Systems ICMEMIS'19. 29-30 June 2019, Djelfa, Algeria.

[38] Berthoz, N. (2012). Modélisation physique et théorique du creusement pressurisé des tunnels en terrains meubles homogènes et stratifiés. Thèse Doc. Ecole Nationale des Travaux Publics de l'Etat.

[39] Berthoz, N., Branque D., Wong, H., and Subrin, D. (2010a). Evolution des champs de contraintes et déplacements autour d'un tunnelier à front pressurisé, Actes des Journées Nationales de Géotechnique et de Géologie de l'Ingénieur, Grenoble, France, pp. 779-786.

[40] Bezuijen, A. (2007). Bentonite and grout flow around a TBM. Proc. ITA 2007, Prague.

[41] Bezuijen, A., and Talmon, A.M. (2008). Processes around a TBM. GEOtechniek – april 2008.

[42] Boubou, R. (2010). Prise en compte du mode de pressurisation du front et de la géologie dans l'étude de l'impact du creusement de tunnels. Thèse de doctorat : INSA de Lyon. France.

[43] Brinkgreve, R.B.J., Broere, W. (2004). PLAXIS 3D Tunnel Version 2, PLAXIS bv, Netherlands.

[44] Brinkgreve, R.B.J., Broere, W., Waterman, D. (2004). PLAXIS 2-D Professional Version 8.0 – User's Manual. PLAXIS b.v., The Netherlands.

[45] Brinkgreve, R.B.J., and Vermeer P.A. (2001). Plaxis 3D Tunnel (Validation manual). Balkema, Lisse. COB. Centre for Underground Construction (1996). Parameterset voor de predicties, COB Report K100-W-004. Gouda.

[46] Broere, W. (1998). Face stability calculation for a slurry shield in heterogeneous soft soils, Proc. Of the world tunnel congress 98 on tunnels and metropolises, Sao Paulo, Rotterdam : Balkema, 1, 215- 218.

[47] Dolzhenko, N. (2002). Etudes expérimentale et numériques de modelé renduit bidimensionnel du creusement d'un tunnel. Développement d'une loi de comportement spécifique. In : Thèse de doctorat : INSA de Lyon. France.

[48] Kasper, T., and Meschke G. (2006a). On the influence of face pressure, grouting pressure and TBM design in soft ground tunnelling. Tunnelling and Underground Space Technology, vol. 21, pp.160-171. 32.

[49] Kasper, T., and Meschke G. (2006b). A numerical study of the effect of soil and grout material properties and cover depth in shield tunnelling. Computers and Geotechnics, vol.33, pp.234-247.

[50] El Houari, N., and Allal M. A. (2014). The Settlement of Soft Soil Caused by Tunneling in Presence of Flow. Electronic Journal Geotechnical Engineering.(EJGE).Vol. 19. 2014, Bund. Z.

[51] El Houari, N., and Allal M. A. (2013). Numerical study of the settlement caused by the tunneling in the presence of the flow Arabian Tunneling Conference & Exhibition 10-11 December 2013. Dubai United Arab Emirates.

[52] El Houari, N., and Allal M. A., and Abou-Bekr N. (2011). Numerical Simulation of the Mechanical Response of the Tunnels in the Saturated Soils by Plaxis. Jordan Journal of Civil Engineering, vol 5, N°01, pp 09-31.

[53] El Houari N., and Allal M.A., and Abou-Bekr N (2008). Ground movement using Plaxis 2D. 20th Canadian Tunneling Conference, Ontario, Canada, 27-28 October 2008.

[54] El Houari N. (2022). Ground movements induced by twin tunneling in soft soil. 5. International social sciences and innovation Congress 12-13 November 2022 Ankara/ Turkey.

[55] El Houari N. (2022). Soil responses caused by tunneling nearby of piles foundations. 8th International mardin artuklu scientific researches conference June 4-6, 2022 / Mardin, Turkey.

[56] El Houari N. (2022). Numerical analysis of the underground works in heterogeneous soil in urban environment. 4. International Palandoken scientific studies congress 28-29 April 2022/Erzurum.

[57] Galli, G., and Leonardi, A. (2004).Three-dimensional modelling of tunnel excavation and lining: Computers and Geotechnics 31.171–183.www.elsevier.com/locate/compgeo.

[58] J. Yin-Fu , Z. Bing-Qing , Y. Zhen-Yu , Z. Dong-Mei. (2019). Three-dimensional numerical analysis of the interaction of two crossing tunnels in soft clay. Journal of Underground Space 4 (2019) 310–327. https://doi.org/10.1016/j.undsp.2019.04.002

[59] Komu M. P., Guney U., Kilickaya . T. E., Gokceoglu C. (2019) Using 3D Numerical Analysis for the Assessment of Tunnel–Landslide Relationship: Bahce–Nurdag Tunnel (South of Turkey). Geotech Geol Eng https://doi.org/10.1007/s10706-019-01084-9(0123456789().,-volV() 0123458697().,-volV)

[60] Leca, E. (2000). Etude du comportement des tunnels creusés en terrains meubles : Laboratoire centrale des ponts et chaussées. Etude et recherche des LCPC, série Géotechnique. GT 66-96 pages. Paris. France.

[61] Moller, S.C. (2006). Tunnel induced settlements and structural forces in linings. Ph thesis, Institute of Geotechnical Engineering. University of Stuttgart (Germany), 174p.

[62] Mollon, G., and Dias D., and Soubra A.H. (2010). Face stability analysis of circular tunnels driven by a pressurized shield. Journal of Geotechnical and Geoenvironmental Engineering 136 (1), 215–229.

[63] Subrin, D. (2002). Etudes théoriques sur la stabilité et le comportement des tunnels renforcés par boulonnage, thèse de doctorat de l'Institut National des Sciences Appliquées de Lyon, France.

[64] Talhaoui Z., El Houari N., (2022). Mechanical behavior of bituminous concrete. 0/14. 8th International mardin artuklu scientific researches conference. June 04-06, 2022 / Mardin, Turkey.

[65] Viggiani, G., and Soccodato, F.M. (2004). Predicting tunneling-induced displacements and associated damage to structures. Rivista italiana di geotechnical, vol. 4, pp.

[66] Allahverdi N, Nasri V (2013). Three dimensional numerical analysis for soft ground tunneling. In: Seventh international conference on case histories in geotechnical engineering, 29 April–4 May, Chicago.

[67] S.G. Ercelebi, H. Copur, N. Bilgin & C. Feridunoglu. Surface settlement prediction for Istanbul metro tunnels via 3D FE and empirical methods. Underground Space Use: Analysis of the Past and Lessons for the Future – Erdem & Solak (eds) © 2005 Taylor & Francis Group, London, ISBN 04 1537 452 9.