

## Prediction of Stresses Around Tunnel in Rock during Advancing TBM

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### ABSTRACT

Drilling machines (TBM) used for civil engineering work in large towns to significantly reduce the harmful effects of expenditure on the earth's surface. The tunneling process complicated due to the dependence of this relationship on construction technology that lead to undesirable consequences such as damage to adjacent structures, so the use of the finite element method has become common to simulate construction stages model using the Hoek-Brown, the methodology includes using the finite element method by constructing the model to predict the behavior of stresses during the tunnel construction stages and to collect the required data so that it is appropriate to the requirements of the region and to analyze the parameters of the numerical model entry and comparing the natural condition of the rocks during the various tunnel construction stages. During tunneling development, vertical stresses at the top and bottom of the tunnel are reduced while horizontal stresses are increased. Three vertical sections are selected to test the TBM tunnel's impact on nearby rocks. The first section ( $x = 0$ ) passes through the center of the tunnel. The second section is near the side edge of the tunnel whereas the third section is more or less selected than the edge of the tunnel. Progression of TBM is reflected through one to five phases. By conducting an axial symmetric FE analysis, the results of math measurement showed major changes in stress that occur in rock regions near the tunnel boundary mostly affects closeness to rocks. This increasing pressure decreases as you step horizontally away from the tunnel and the seams achieve exceedingly small values for lengths greater than 12 m from the edge of the tunnel.

## 1. Introduction

The essences of surrounding rock's stability analysis are the study and assessment of the rock mass medium, the relationship between stress and strain. A significant number of engineering activities indicate [1,2], the stability of rock surrounding tunnels is correlated not only with the consistency of geological structure and groundwater, but also with the excavation and support of tunnel of time and shape tunnels.

The rock's stability is not only determined by the rock's strength but also relies on the quality of the rock's surrounding structure. The

rock mass structure is divided into five categories: complete structure, block structure, catalectic structure, layers, and granular structure, these are also the main types of tunnels circling the horizontal rock structure[2].

The horizontal layered structure's rock mass is a simple sedimentary rock that can consist of a single lithology and can also be formed by combining different lithological layers. The degree is often the poor intercalated sliding between the connecting layers, the damage mostly to the subsidence, and separation at the top curve. When the subsidence is through,

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broken layers appear to fail. Wide period underground cavern excavation is covered in porous rock, and the more prevalent issue is surrounding rock stability.

The comprehensive effect of rock stability tunnels depends on several factors, the key factors are: physical and mechanical properties, rock mass structure and construction, natural rock mass stress condition and geological structure control, groundwater, rock under static and dynamic load, tunnel geometry and construction scheme.

Based on the factors affecting the stability of tunnels surrounding rock, the factors influencing the surrounding rock stability of tunnels in horizontal stratum area can be summarized into three types[3]: (1) geological influences: rock stress, rock physical and mechanical properties, rock structure, rock composition and physical and chemical properties, etc.;(2) engineering factors: tunnel shape and size and high-span ratio; (3) construction factors: tunnel construction methods, time support and support methods, etc. The main factors influencing the stability of surrounding rock are the geological factors.

Tunnel building is necessary and the development of underground space is part of the infrastructure to tackle the increasing issue of urban mass rapid transit. The method of numerical modeling of the tunnel construction based on the finite element method is used to evaluate the ground movement inducing tunneling which is essential to predict settlement through construction and its effects on adjacent buildings. A method of prediction of surface settlement is based on field data and results of numerical modeling of the construction phases. In this study, Mohr-Coulomb predicts the stress caused by the simulation model tunneling using a numerical method (FEM)[4]. A system for the study of finite elements requires a pre- and post-processing step. The former includes various modules to construct a model, to define material properties, to determine boundary conditions and external loads, and to mesh the model assembly. The results obtained from the analysis can be large, so additional processing that

represents the latter step is needed. The computational modeling procedure which uses the FEM broadly consists of main steps: geometry modeling, meshing (discretization), material property specification, boundary specification, initial and load conditions. Several steps required for a Finite Element Method are defined in the following[5]. The first step is crucial, because it is the presumption that the "true problem" must be idealized. The problems studied with the finite-element approach are usually real-life 3D problems, but can be reduced to 1D, 2D or 3D models. Simplifying the model will achieve this reduction in dimensions. This initial phase can alter the results dramatically; hence a valid assumption should be made before modeling begins[5]. It is possible to reduce the 3D to 2D by inputting the third dimension or by actually considering the most important part of the 3D problem as a parameter. The 2D analysis can be based on the following approaches: plain stress, plain strain and axisymmetric.

The Elastic Beam (Hetenyi-solution, 1946) Changes to various spring constants representing soil and boulder strength properties and numerically analyzes the problem using the STAAD-Pro/2004 software in the FE system. The normal stresses and strains in concrete footing must inevitably shift, the case that this study can reveal. In other words, the analysis concerns the distribution of stress in soil with the involvement of boulder and its modeling as spring forces in the FE system, and how these induced forces shift the stresses and strains in the concrete footing by contrasting them with the non-boulder existence[6].

In civil and rock engineering, digital modeling is receiving more attention to predict the rock mass response to various drilling activities[7]. Numerical methods are simple, less costly, and less time-consuming to evaluate redistributive stresses and their impacts on rock mass behavior and structural design are at the core of the environmental stone block. Numerical methods Mathematical equation rest in problems of governance and engineering Physical and strong determinants of rock parameters Input parameters [8,9].

Estimating site stresses generally requires detailed geological descriptions of the site and considerable judgment. Models (physical or numerical) can be developed to explore the influence on site pressures of parameters such as the foundational model of the rock, loading date, critical geological structures, terrain, and boundary conditions. It is common practice to make two fundamental assumptions when estimating the stress state in a rock mass at any depth,  $z$ . The first hypothesis is that the stress condition can be defined with two components: vertical component ( $\sigma_v$ ), due to the excess weight of the rock at this depth equal to  $\gamma z$ , A uniform horizontal component,  $\sigma_h = (\sigma_H \text{ equals } K \text{ times } \sigma_v)$ . The second assumption is that the two main stresses are both  $\sigma_v$  and  $\sigma_h$ . Another expression sometimes used for the coefficient of  $K$  in the literature is  $K_o = \nu / (1 - \nu)$  where  $\nu$  is the rock's Poisson ratio.

This expression was derived from the assumption (1) that the rock mass is half an ideal linear homogeneous linear parallel area with the horizon surface, (2) that the rock mass is alone under gravity with the disappearance of

horizontal positions, and (3) that the loading record has no effect on how it accumulated pressure at the site[10]. This study's main objective is to predict the horizontal and vertical stresses around the tunnel during advance tunneling with TBM improvement in the rocks.

## 2. General procedure of modeling

PLAXIS 's general modeling technique is to define engineering with elements and materials, define loads and boundary conditions, create a FEM grid, define initial conditions, and perform FEM calculations consisting of a staged construction. By dividing the underground into layers, structural elements, loading and building phases, the importance of analyzing each project is to create an engineering model that represents a true three-dimensional representation.

Consisting of points, lines, and groups. The model should be dimensional enough in that the boundaries do not affect the result of the problem as described in (PLAXIS-3D Manual, 2013). Figure1 shown the methodology of research.

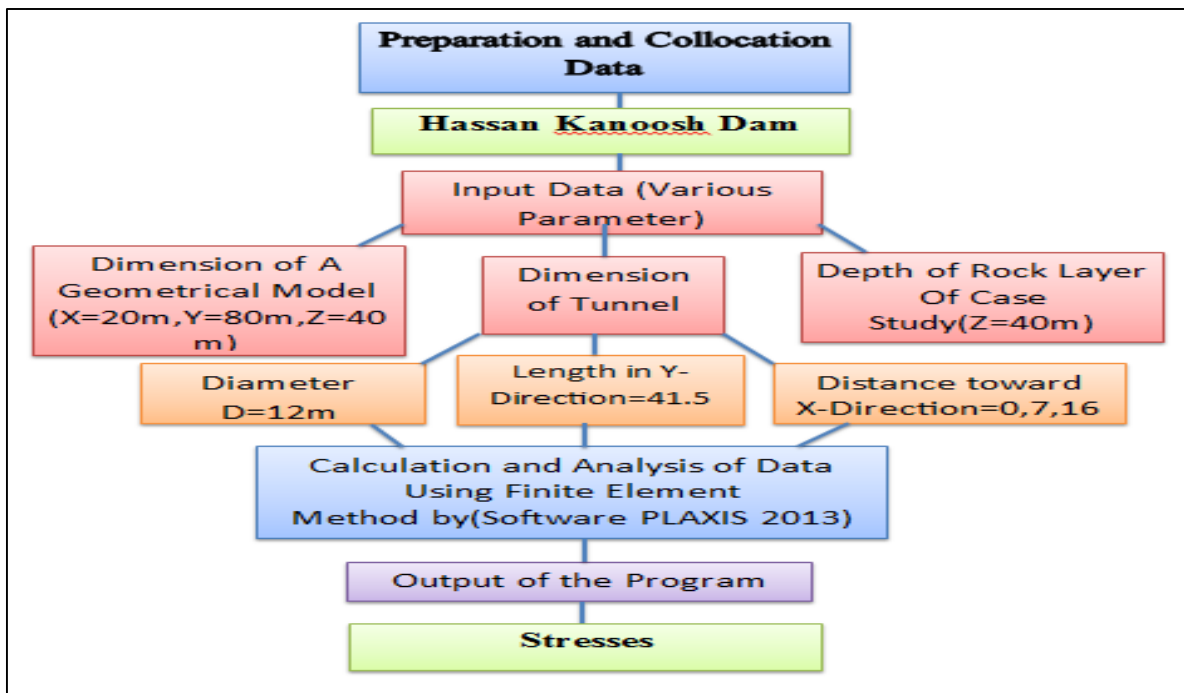


Fig.1. Flowchart of Methodology of Research

### 3. Case Study

The object of a mechanical tunnel model's numerical analysis is to take into account the large number of operations undertaken during excavation and construction of the tunnel. The 3D object model consists of various components, such as rock parameters, rock layers, tunnel boring machine, hydraulic jacks, tunnel liner application, all of which are analyzed and simulated in the 3D FEM model.

#### 3.1 Model Dimensions and Rock Properties

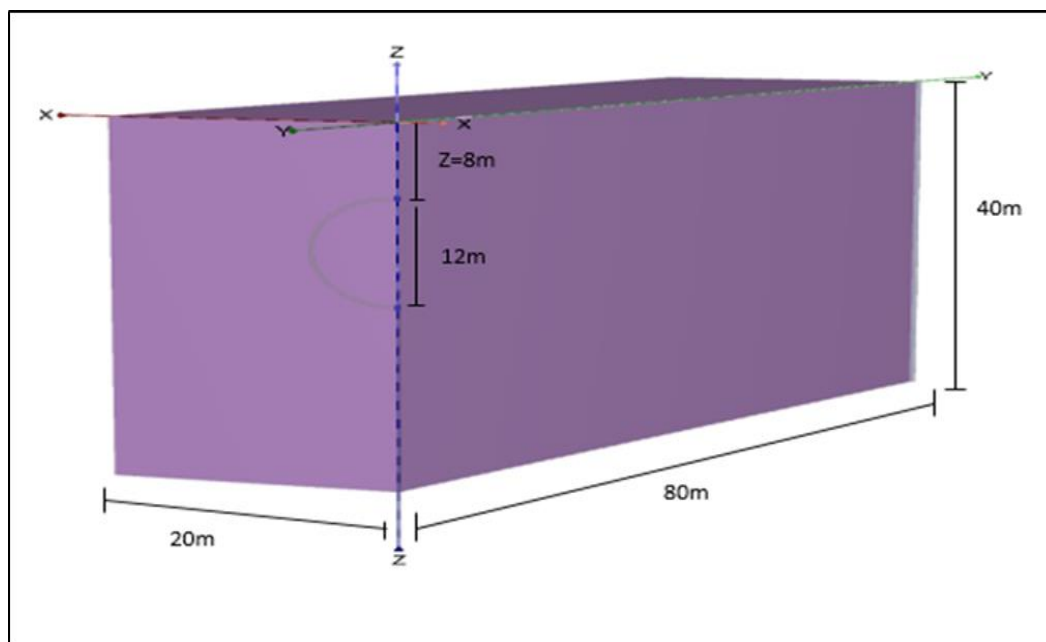
The tunnel construction simulation is performed using FEM, and because the model is symmetrical,

a number solution takes half of the tunnel model for calculations. The tunnel diameter (D) assumes 12 m and its length is 9 m. Figure 2 shows the geometric shape of the tunnel and its estimated network. The model of the tunnel depends on the actual properties of the rock. From the basic tests on the project's rock hole the criteria obtained and some other standards were adopted from [11].

The collected data from the project field and laboratory tests can be seen in Table 1. In this study the model used to be the rock behavior is the Hoek-Brown model (HB).

**Table 1** The rock parameters of the Hoek-Brown model (HB)

Depth(m)	40
Saturated unit weight of rock (kN/m <sup>3</sup> )	23
Unsaturated unit weight of rock (kN/m <sup>3</sup> )	23
Young's modulus×10 <sup>6</sup> * (kN/m <sup>2</sup> )	14
Uni-axial compressive Strength×10 <sup>3</sup> * (kN/m <sup>2</sup> )	25
Intack Rock parameter*	4
Geological Strength Index*	38
Disturbance factor	0
Poisson's Ratio *	0.3



**Fig .2.** The geometry of the tunnel for the 3D model

### 3.2 Type of element used in numerical study

In engineering problems (geotechnical problems) and to obtain precision, the grid with the nested four-dimensional nested elements is used for the three-dimensional finite element and is also used to model the tunnel lining. The functions of the form which have the component size equal to the unit in node *i* and zero in the other nodes. Interface elements consist of interface

elements that are observed at a limited thickness in some program output diagrams, but in the formulation of the finite element (FE), the coordinates of each node pair are identical, meaning that the interface element is zero thick. Trigonometric elements' stiffness matrix depends on the characteristics defined in the material data sets that were acquired through Gaussian integration using 6 integration points as shown in Figure 3[11]

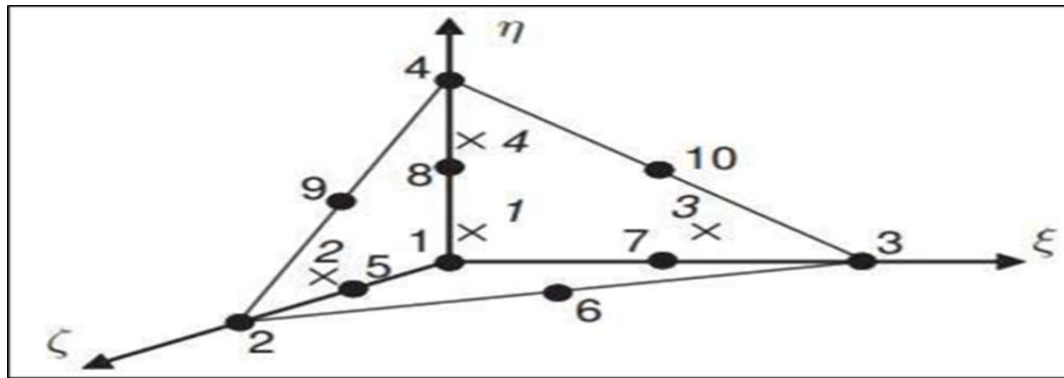


Fig .3. Local numbering and location of nodes (•) and integration points (x) of tetrahedral elements shape [11]

### 3.3. Structural elements properties

TBM (tunnel boring machine) is designed as plate elements and should be 9 m long and is designed as plate elements for the segmental tunnel liner. Table 2 describes the tunnel system parameters[12]. Portion is believed to be 1.5 m

wide each part in the concrete lining used, and hence TBM advances 1.5 m at each tunneling stage frequency. The concrete lining segments are formed by the application of structural elements with flexible linear behavior of the properties formed. Table 3 presents the material properties of lining elements.

Table 2 Material of properties of the TBM [11]

Parameter	Unite	TBM
Thickness	Meter	0.35
Elastic Modulus	(kN\m <sup>2</sup> )	23.0*10 <sup>6</sup>
Unit Weight	(kN\m <sup>3</sup> )	70
Poisson's Ratio	-	0.1

Table 3 The material properties of the concrete lining element

Parameter	Unite	Lining	TBM
Thickness	Meter	0.25	0.35
Elastic Modulus	(kN\m <sup>2</sup> )	23.5 *10 <sup>6</sup>	23.0*10 <sup>6</sup>
Unit Weight	(kN\m <sup>3</sup> )	25	70
Poisson's Ratio	-	0.1500	0.1

The volume of the face pressure is measured in this paper about the vertical pressure generated by the weight of the rock deposits and is related to the unit weight of the bentonite suspension, while the volume of the pressure was described by the face pressure at the tunnel 's crown. The filling pressure rises linearly from the tunnel 's crown to its reversal as a face pressure depending on the unit weight of the plaster content. The first six drilling steps reflect a 9-meter advance at long TBM and the veneer elements are enabled using the dedicated TBM content, the liner is then fixed by setting the liner material to the respective veneer elements[11].

#### 3.4. Mesh generation

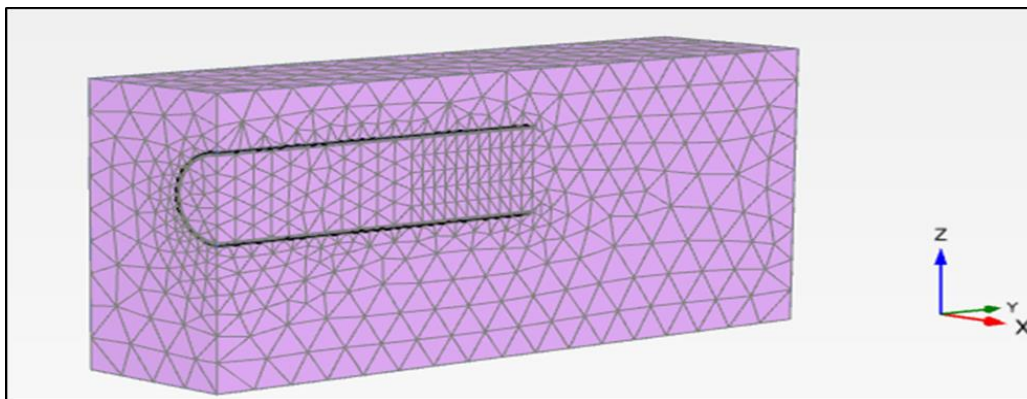
An unstructured, automatically created network is used in PLAXIS 3D which can be selected to boost the local and global network. PLAXIS 3D displays five choices for spreading

network density from a very rough mesh to a very fine mesh. A Medium Network is implemented in this article. The network is streamlined in areas where high and critical stresses and strains are required, i.e. the tunnel, tunnel liner, and surrounding rocks, as shown in Figure 4.

#### 4. Results and discussion of numerical model

The modeling method for building a tunnel using TBM is a description of the construction stages that include drilling rock and installing a

lined concrete portion. The results obtained from rock tunnel pressure using a finite element method with rock failure criteria are the HB model, showing the position of tunnel model sections at x-direction as shown in figure5.



**Fig .4.** Medium type mesh of 3D geometrical of the tunnel for (HB) model

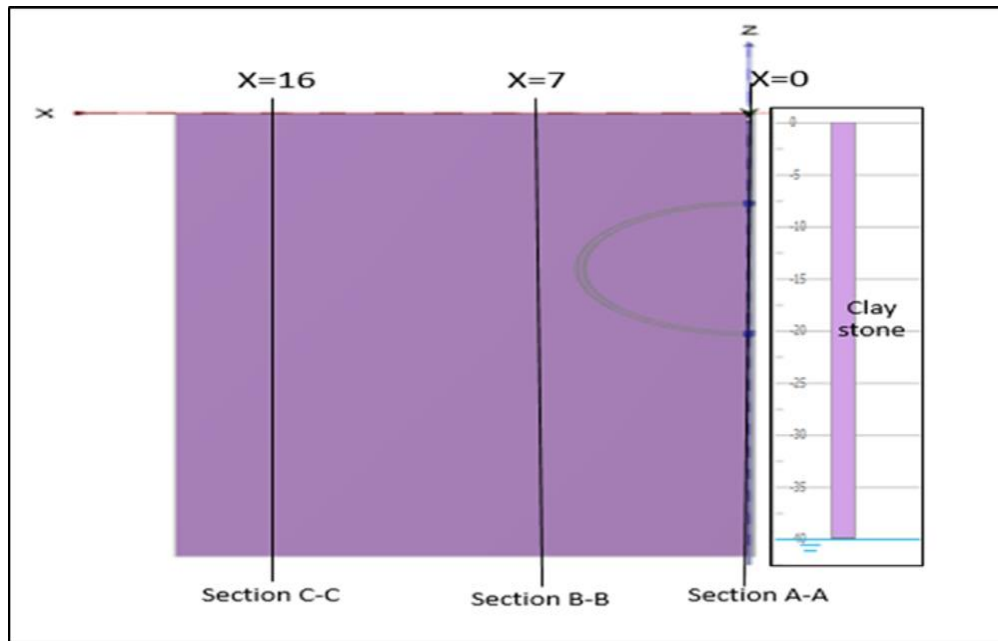


Fig .5. Displaying location of sections taken tunnel model at x-direction

#### 4.1 Stresses of section A-A

This section describes tunnel data ( $x = 0$  with variations in direction of  $Y = 26.5$  m, and different depths  $z$ ). It should be noted that in this case, the curves of the stress depth indicate the vertical and horizontal stress at different depths, while deviations  $y$ -direction = 26.5 and  $x$ -direction = 0 with deviations. The first stage marks the beginning of the TBM construction work and the excavation of the first section of the tunnel liner, in addition to the further steps that will serve as a model for the 1.5 m wide.

Figure 6 indicates the distribution of vertical pressures during the tunnel model's construction phases. The vertical pressure usually decreases from all stages with increasing depth. As TBM progresses in rocks, vertical pressure from the upper tunnel area starts to be 65% lower than the initial rock. That's because of TBM's system vibration and side pressure effect. In the area

below the tunnel, the vertical pressure of all stages is 46% lower than the original rock and becomes similar to the original rock with increasing depth as the area is far from the tunnel effect.

Figure 7 reflects the complete horizontal distribution of the pressure during the tunnel model building. In general, the horizontal pressure increases with increasing depth from the original rock and all the stages. As TBM progresses in rocks, the upper tunnel area horizontal pressure begins 33 % more than the initial rock. This is due to the mechanical vibration of TBM and the effect of the horizontal ratio  $k$ . For the area under the tunnel, the horizontal pressure of all stages is 20 % lower than the original rocks about depth 20m, then the horizontal pressure of all stages begins to increase by 16 % from the original rocks and becomes close to the original rocks after a depth of 30 m because the effect of the tunnels behind this depth is not significant.

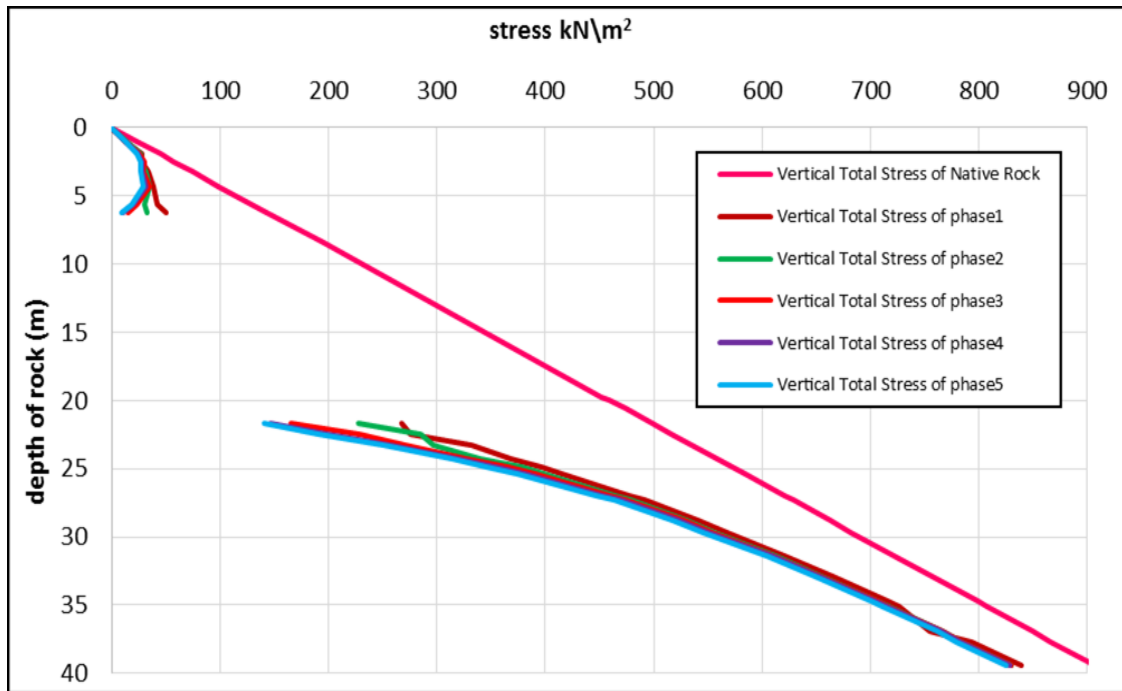


Fig.6. Distribution of the total vertical stress during construction phases of tunnel at x=0 with find deviations

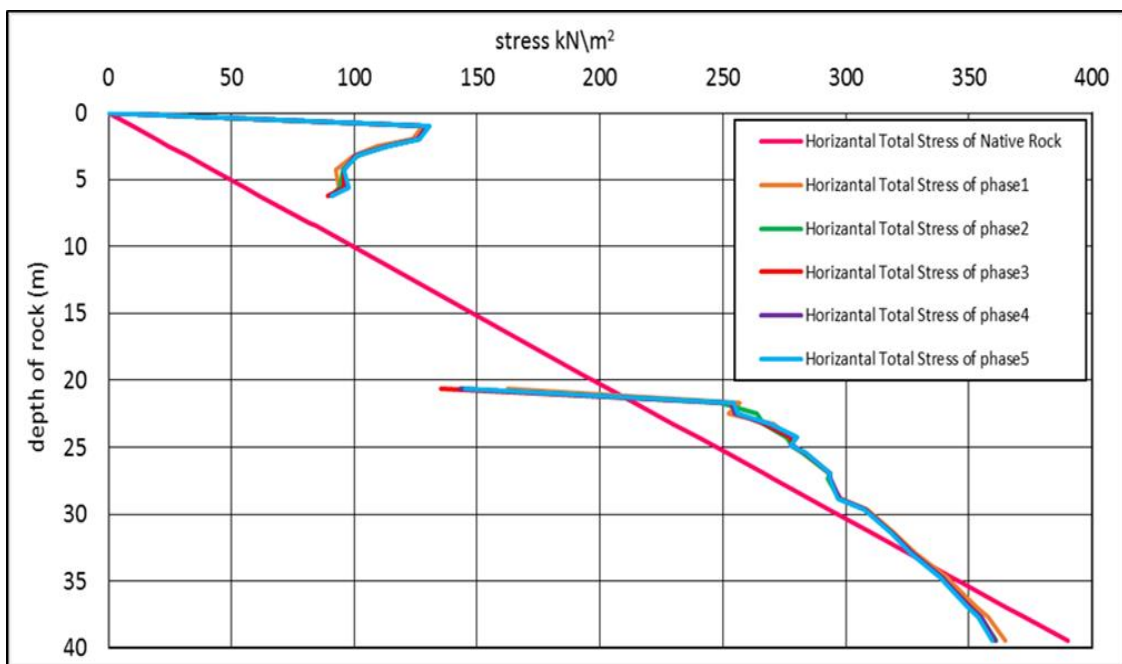


Fig.7. Distribution of the total horizontal stress during construction phases of tunnel at x=0 with find deviations

#### 4.2 Stresses of section B-B

Figure 8 shows that the vertical stress increases with the increase in depth to the original rocks and all stages. As TBM advances in rocks, differences in vertical stress begin approximately 5 meters from the Earth's surface. For the area between depth (5-22) m, the vertical pressure of

all phases is 37% more than the original rock. This is due to the tunnels dug in this area and the effect of side pressures. Also, in the region at depth (22 m) or more, the vertical pressure of all stages begins to decrease and becomes 8% less than the original rock. This is due to the side forces induced from the TBM machine. Away from the depth of



30 m, the vertical stress of the original rock and all stages converge, the influence of tunnels is not significant behind this depth.

It is evident from figure 9 that the horizontal stress at the top of the tunnel will show the same deflection behavior at all phases. As for the area between the depth (10-20 m), the horizontal stress of the first and second stage is greater than the horizontal stress of the initial rock in 31 % where the first stage reaches the highest deviation at 16 m depth followed by the second stage. As for the rest of the stages, their conduct is similar or their deviations are less or less than the original rocks due to the tunnel in this area and the effect of the horizontal ratio, but at depth (20 m-30 m) the horizontal stress is the same for all stages and is lower than the horizontal stress of the original rocks in 5%. The horizontal stress of the original rocks converges with all phases at depth (30–40 m), as the tunnel effect behind this depth is not important.

#### 4.3 Stresses of section C-C

In this section the distance from X-direction = 16 m Y-direction=26.5 m and different depth of Z. From Figure 10 it is clear that the vertical stresses of all stages are identical to the original rock, as this region is far from the drilling point. Figure 11 The overall horizontal stress behavior can generally be observed and is similar to the behavioral trend for all stages with a slight difference between all stages; the horizontal stress of all stages is less and more due to the horizontal stress of the original rock with increased depth. This is due to several reasons, such as the distance from the machine vibrations (TBM) during drilling (the horizontal ratio (K) effect, in addition to some of the long-distance deviations (x) adopted around the tunnel area).

#### 4.4 Stress ratio (k)

##### 4.4.1 at X=0

This segment describes tunnel data (x = 0 varying in direction y = 26.5 m, and various depths z). It should be noted that in this case the stress

ratio curves (k) with depth indicate the stress ratio (horizontal stress / vertical stress) this value used to determine the condition of rock (passive or active) at different depths, while the direction y = 26,5 with deviations and the direction x = 0 with the deviations. The first stage marks the beginning of the TBM construction work and the drilling of the tunnel liner's first part, in addition to the following other phases which will serve as a 1.5 m wide model.

Figure 12 reflects the distribution of the stress ratio during tunnel model construction. In general, the stress ratio for all stages (passive zone) in the upper part of the tunnel is very large, with a value in the fifth stage of more than 5. As for the other phases, the stress ratio values range from 2.3 to 5, which is higher than the stress ratio in the original rocks, at the bottom From the tunnel (passive zone), the stress ratio values in the fifth stage are also large with a value of approximately 1.8 and the rest of the stages, the stress ratio values range from 0.9 to 1.5, and the stress ratio values for all stages converge with the stress ratio values for the original rocks as the depth increases and correspond after the depth of 35 m because the tunnel effect is not significant.

##### 4.4.2 at X=7

This section represents tunnel data (x = 7 with variations in direction y = 26.5 m, and different depths z). It should be noted that in this case, the stress ratio curves (k) with depth show the stress ratio (horizontal stress / vertical stress) at different depths, whereas the direction y = 26.5 shows the deviations and the direction x = 7 shows the variations. The first stage marks the beginning of the TBM construction work and the drilling of the tunnel liner's first part, in addition to the following other phases which will serve as a 1.5 m wide model.

Figure 13 describes the distribution of the stress ratio during tunnel model construction. In general, the stress ratio for all stages (passive zone) in the top part of the tunnel is greater than the stress ratio in the initial rocks where the stress ratio for all stages is more than 1.2. For depth (5-25) the stress ratio for all stages (active zone) is less than the

stress ratio in the original rocks, in the lower part of the tunnel after the depth of 25 m the stress ratio for all stages with the depth converges with the

stress ratio values of the original rocks and corresponds to them after the depth of 25 m because the impact of tunneling is not important.

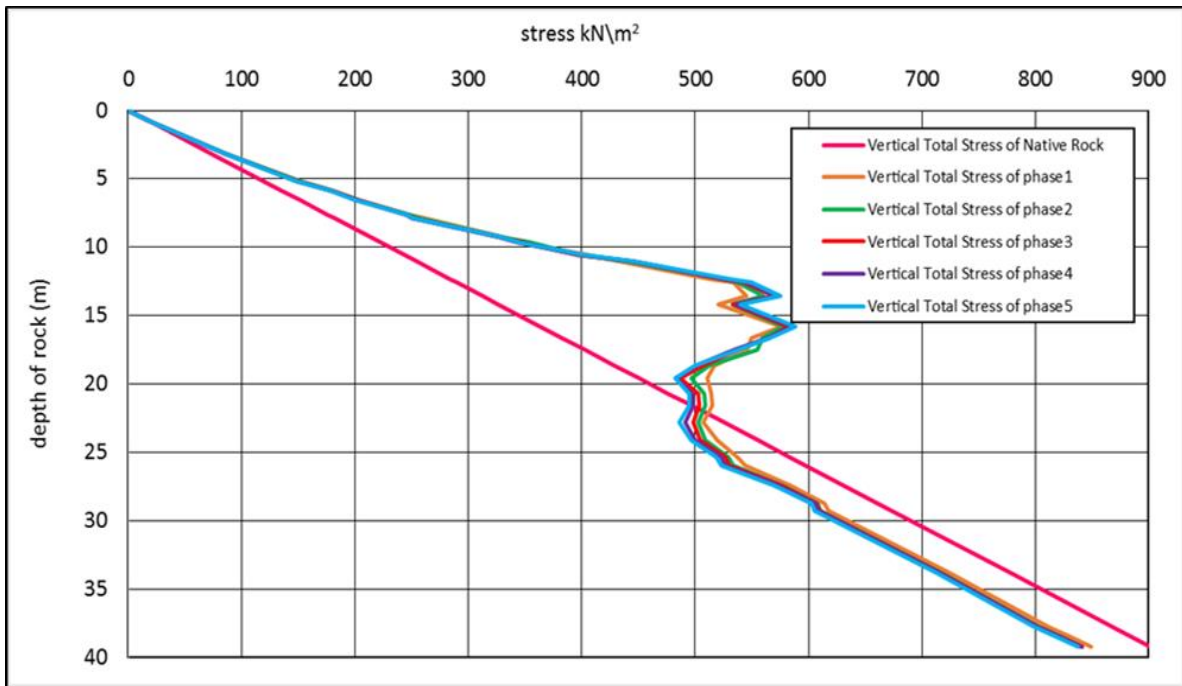


Fig 8. Distribution of the total vertical stress during construction phases of tunnel at x=7 with find deviations

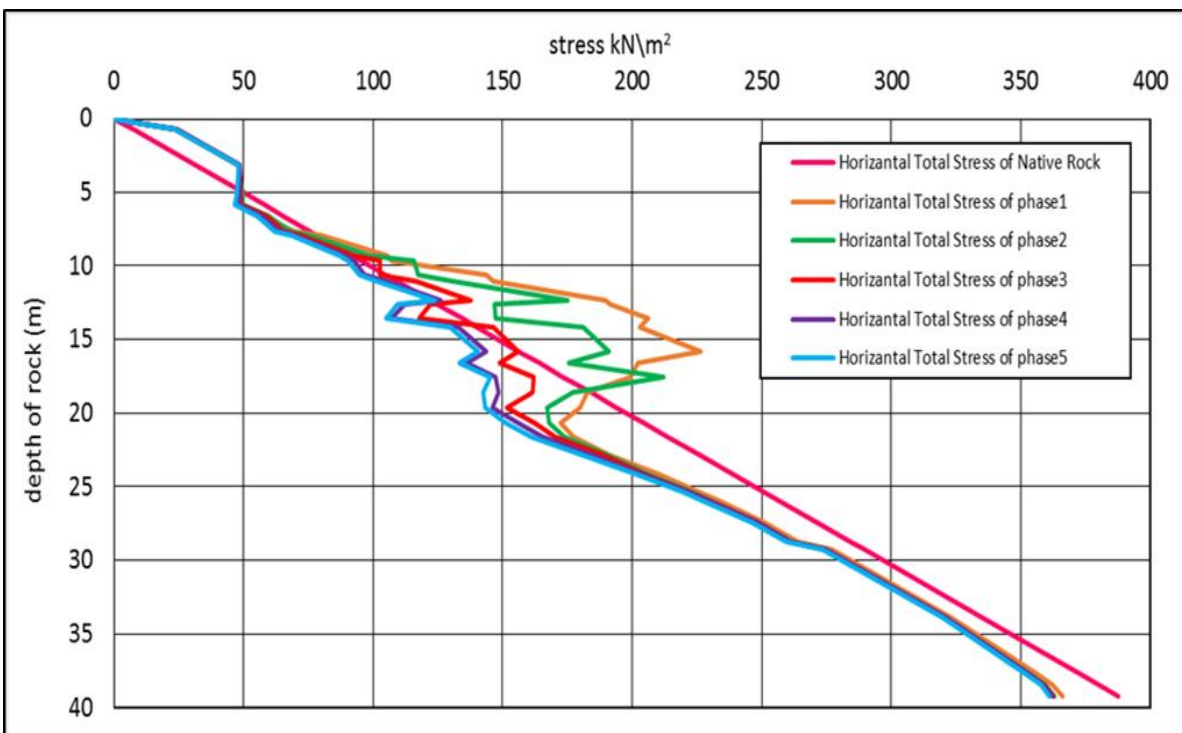


Fig 9. Distribution of the total horizontal stress during construction phases of tunnel at x=7 with find deviation

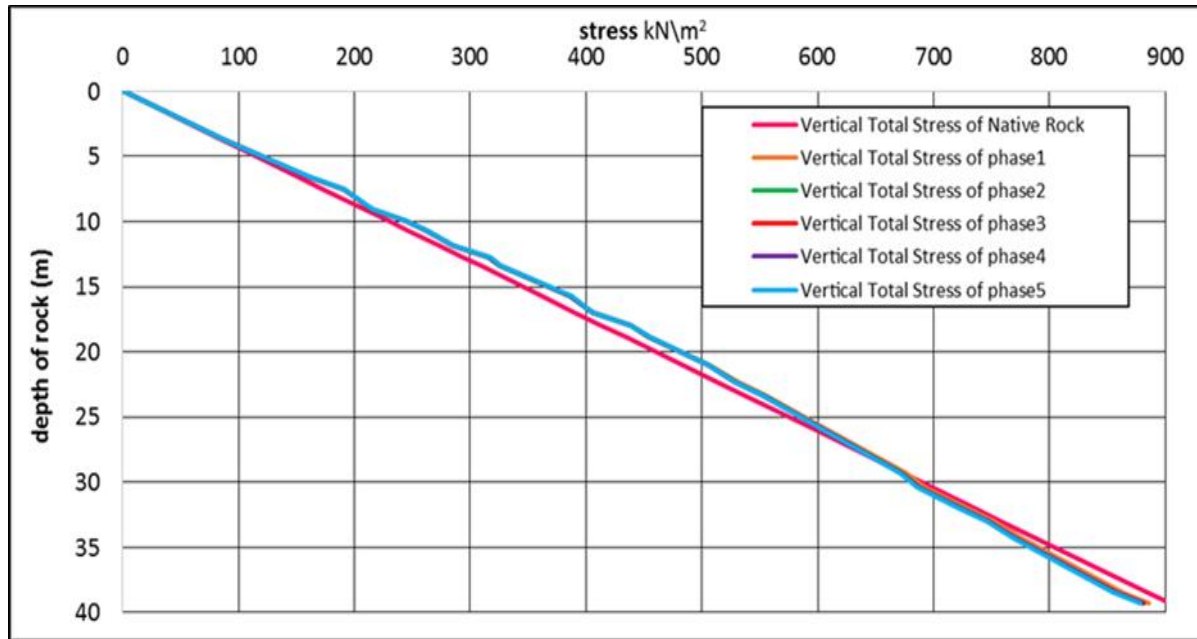


Fig 10. Distribution of the total vertical stress during construction phases of tunnel at x=16 with find deviation

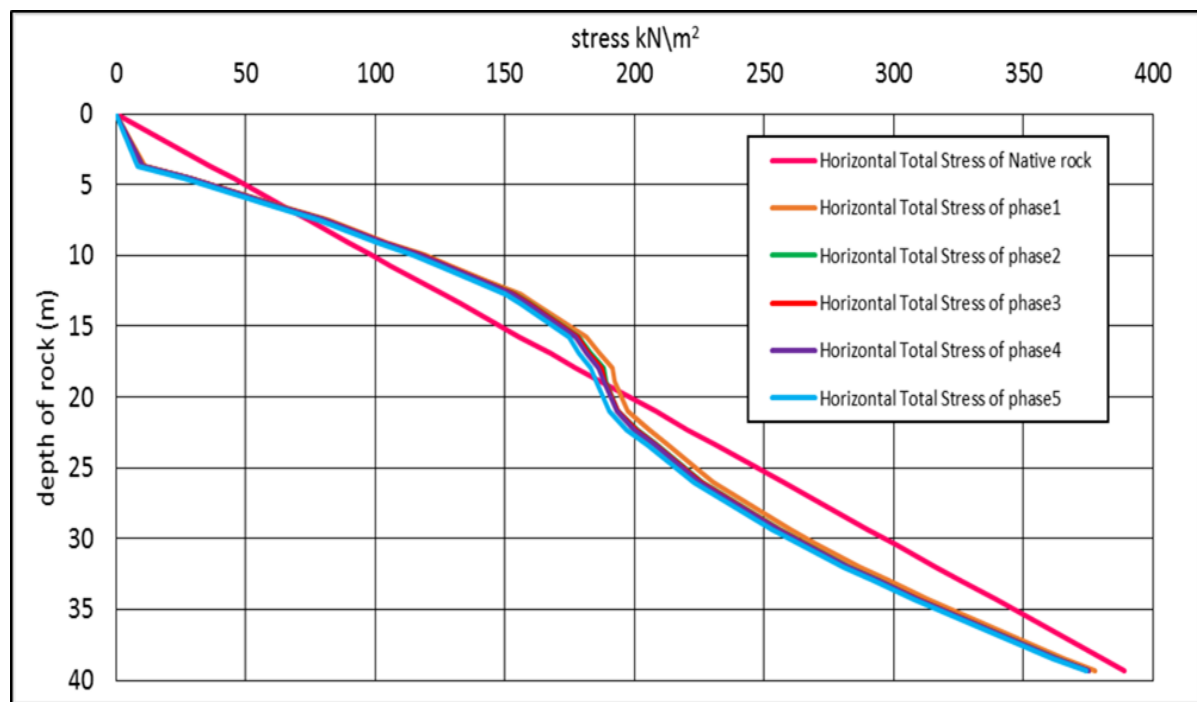


Fig 11. Distribution of the total horizontal stress during construction phases of tunnel at x=16 with find deviations



Fig 12. Stress Ratio during construction phases of tunnel at  $x=0$  with find deviations

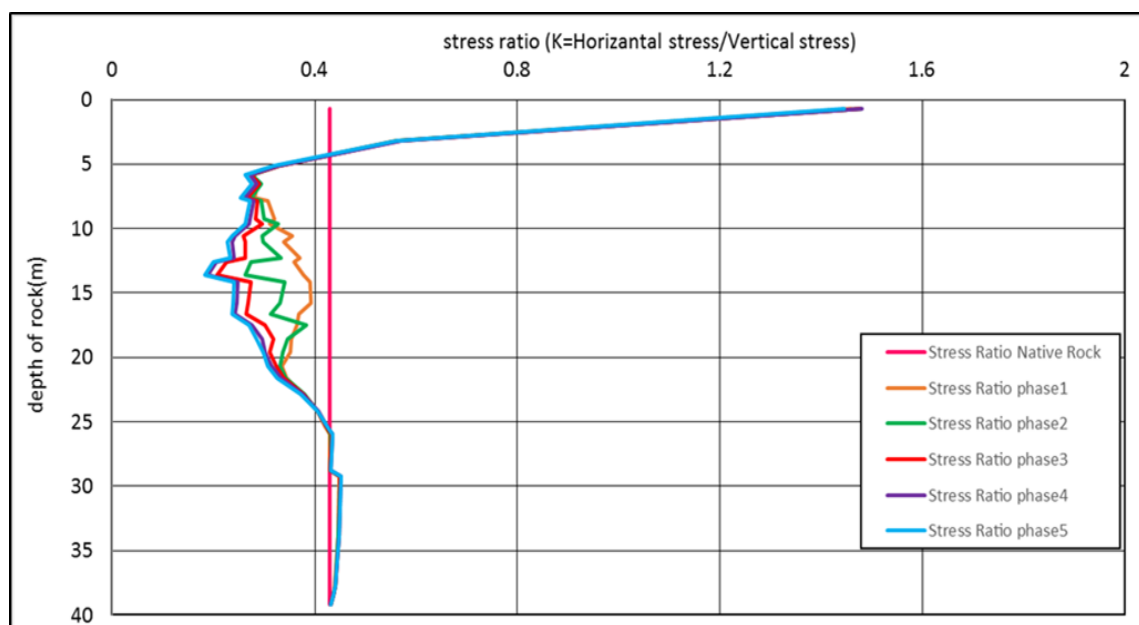


Fig 13. Stress Ratio during construction phases of tunnel at  $x=7$  with find deviations

## 5. Conclusions

The analysis in this study focuses entirely on the difference of state (pressure) before and after the TBM construction. So, all the curves shown in the research indicate rock stress conditions for pre-drilling (original rock condition) with rock stress during tunnel construction. The author claims that the most important thing is what will change in the rocks before and after the tunnels are dug. The current FE software does not endorse promoting the distribution of digital and technological

information through the rock body, but PLAXIS only provides information at the nested node level. The rocks around the tunnel are witnessing the greatest changes to stress. These adjustments (or site pressure deviations) are recorded in relation to the site conditions  $x = 0$ ,  $x = 7$ ,  $x=16$ . They draw the following points:

The analysis in this study focuses entirely on the difference of state (pressure) before and after TBM construction. Therefore, all the curves shown in the research indicate the conditions of

pre-drilling rock stress (original rock state) with rock stress during the construction of the tunnel. The author claims that the most important thing is what will change in the rocks before and after digging the tunnels. The rock around the tunnel is experiencing the biggest pressure changes. These adjustments (or site pressure deviations) are recorded in relation to the site conditions  $x = 0$ ,  $x = 7$ ,  $x = 16$ . They draw the following points:

1. The stress values are large within the tunnel area as a result of the vibrations of the TBM drilling machine, and these values decrease or fade whenever we move away from the tunnel area. For example, at section  $X = 7$ , the stresses are high and at section  $X = 16$  the stresses diminish or decrease, as the area is far from the effects of the tunnel. converge with the stress of the original rocks for all stages.
2. The progress of in the upper part of the tunnel, the stress ratio values are high, up to 5, which is a passive area, while below the tunnel is an active area, and the stress ratio values converge with the original rocks as the depth decreases away from the tunnel.

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