The influence of Temporary Support System type on the Settlements Induced by Shallow Urban Tunneling (Case of study: Gallery of Metro Station)

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ABSTRACT: Construction of underground metro stations may faces several problems in urban design terms. Therefore, design engineers use a variety of support system to stabilize the structure and ensure workers safety. In this study we present the results of 2D numerical simulation of the western gallery of underground metro station taking into account the influence of temporary support system type on the settlements induced by shallow urban tunnelling. The results obtained show that the use of different lining types and ground improvement minimize the horizontal and vertical displacement.

Keywords: underground station, support system, settlement, urban areas, 2D numerical simulation.

1 INTRODUCTION

Depending on a modern public transport system. ; Algiers's government aims to unite far-flung parts of the city and in the other hand rescue the capital from a severe congestion that may threatens its future growth.

Every day of construction, the engineers confront the danger of mechanical failure, fire and collapse. Temporary support systems plays a paramount role in ensuring workers safety; a lot of researches; which in numerical methods has proven to be the most reliable method; has been conducted to highlight the importance of different support systems in controlling ground deformations during tunnel construction. For instance, the use of a forepoling umbrella system has been shown to effectively mitigate ground surface settlement by developing radial and longitudinal arching around the tunnel opening. (**Zheng Jinlong and al**)

Research indicates that pre-support can significantly reduce displacements, often more effectively than temporary supports alone. However, the contribution of pre-support to overall stability can sometimes overshadow the benefits of temporary support systems (**O N Eveny1* and al.**).The most of researchers believe that the temporary support is of great importance. It reduces displacements and plastic strains at the crown and also relieves developed lining forces, which results in higher excavation face stability, provides significant limitations of ground settlement and increases excavation work safety by strengthening the tunnel crown.

In a nutshell; we aim to investigate the influence of temporary support system types on the settlements induced by shallow urban tunneling, using Finite Element Method software "Plaxis 2D".

2 ENGINEERING BACKGROUND

2.1 *Geographical location*

The Beaulieu Station project is situated to the east of Algiers city, “OUED SEMAR” province, Algeria. It is located in a topographically plain area under the intersection of two roadways, namely, Boulevard “SIDI OKBA” and “Avenue AHMED HAMIDOUCHE”.

Once completed, the tunnel will connect GARE EL HARRACH with the new terminal of the international airport “HOUARI BOUMEDIENE”. The surrounding environment of the tunnel construction is relatively complex. There are several nearby buildings. To the north of the station, there is a residential area with seven storeys. To the southwest of the respective technical zone, there is the technical “EL BIROUNI” high school, which consists of one or two storeys buildings. Finally, to the southeast of Beaulieu station, there are three buildings (one to two storeys) that are part of the police station.

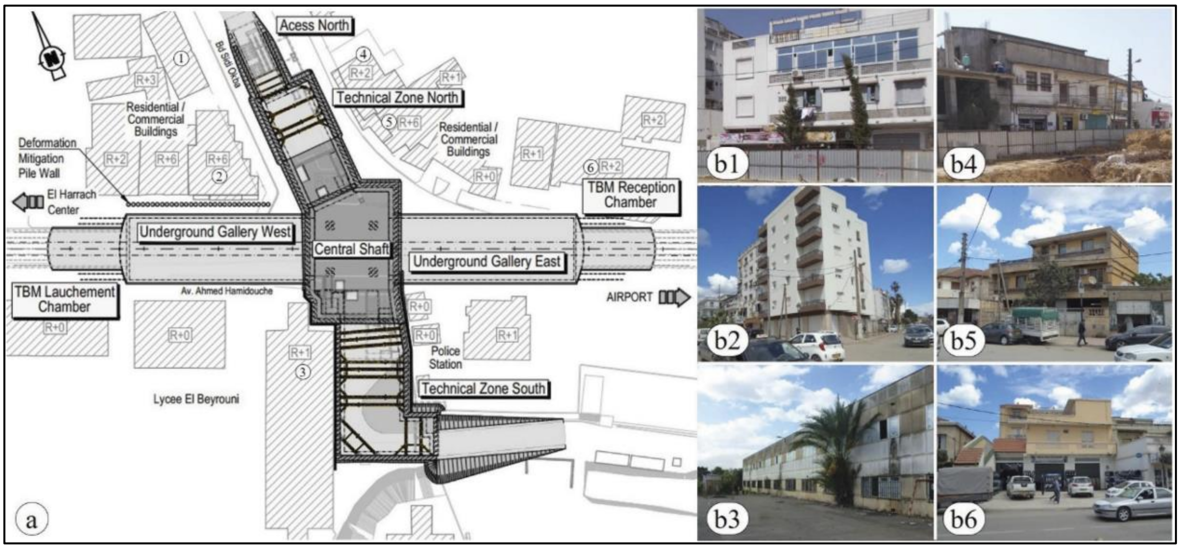


Fig. 1: Beaulieu Station location (a) and nearby buildings (b).

In this study we take into account only the excavation of the western gallery.

Table. 1 : Western Gallery dimensions

L (m)	Φ (m)	OH (m)
50	19	10.2

2.2 *Construction process*

- **Excavation methods**

The western gallery is excavated using the NATM (a partial face excavation method) (Fig. 2).

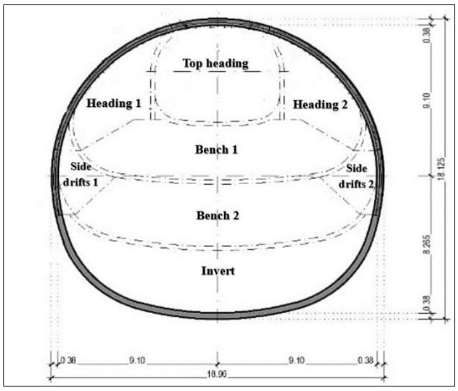


Fig. 2: Excavation parts

The tunnel excavation is initiated after initial support or improvement of ground strength above and around the crown of the tunnel face. Based on the design, excavation and installation of the initial (primary) and temporary support systems of the tunnel is executed in 5 stages, as illustrated in Fig. 3.

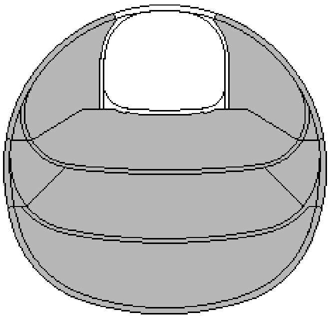
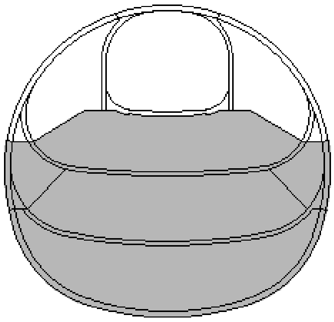
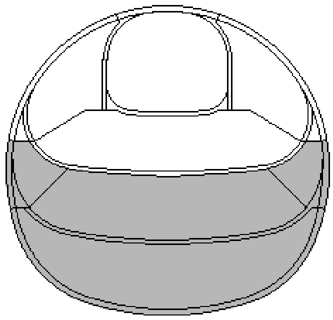
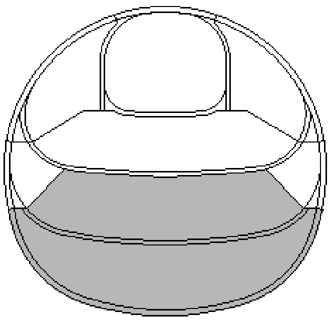
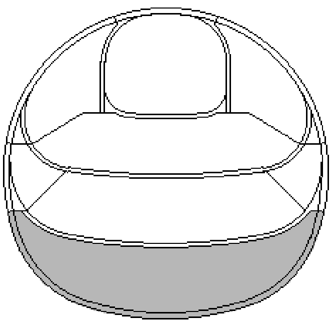
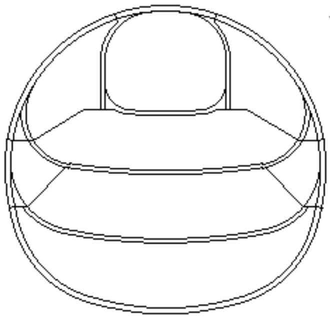
 **Phase 2:** *top heading excavation followed by the installation of the suitable temporary support.*	 **Phase 3a:** *alternatingly excavations between the two remainder of headings*	 **Phase 3b:** *Excavation of the first bench and temporary invert execution*
 ***Phase 4a:*** *Alternatingly excavation of the two Side drifts*	 **Phase 4b:** *Excavation of the second bench*	 **Phase 5:** *Excavation of the invert and temporary support execution*

Fig. 3: Typical scheme of excavation sequences of the underground gallery

- **Geological features**

Based on data collected from 11 boreholes, laboratory tests; insitu investigations, and hydrological characterization we have determined the ground stratigraphy. The onsite geological layers are shown in Figure 4.

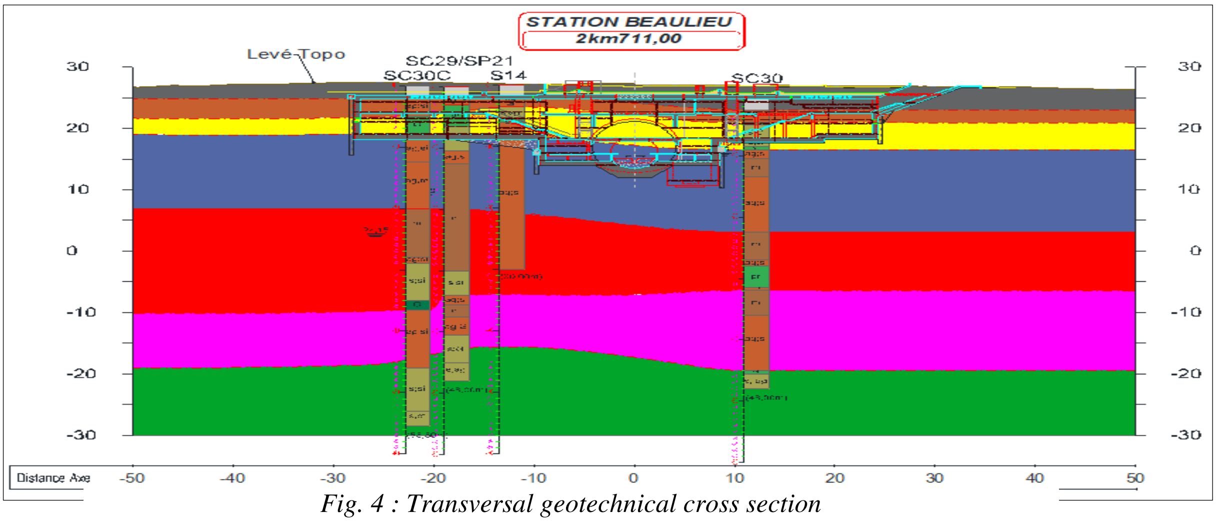


Fig. 4 : Transversal geotechnical cross section

- **Idealized Geological Profile parameters**

The design parameters values were established based on the mean value approach, so we have calculated the mean values of the relevant parameters

Table. 2: Idealized Geological Profile parameters

Geotechnical horizon	Embankment E	Clay Qa	Clayey sand Qs	Clayey marl QM	Sandy marl QMs	Marley clay QMa	clayey sand with pebbles and conglomerate intercalations QSg
Medium depth (m)	0-3.5	3.5-4.5	4.5-13.5	13.5-28	28-37	37-41	>41
Wet unit weight γh (KN/m3)	-	20.81	19.38	20.47	20.46	20.46	19.38
Dry unit weight γd (KN/m3)	-	17.11	17.20	17.03	17.09	17.09	17.20
Undrained-cohesion Su (Kpa)	-	51.00	69.00	71.50	79.75	79.75	69.00
Undrained deformability module Eu (MPa)	-	57.05	50.70	43.39	37.81	44.04	34.96
Effective friction angle ϕ' (°)	-	50.25	42.00	54.88	54.88	54.88	42.00
Effective cohesion C' (Kpa)	-	50.25	42.00	54.88	54.88	54.88	42.00
Drained deformability module E' (MPa)	-	49.61	-	37.73	32.88	38.30	-
Coefficient K0	-	4.15E-07	-	3.06E-06	3.06E-06	3.06E-06	-

After a thorough ground characterization; the idealized geotechnical profile for the simulation was constituted of “2 layers of sand and one of clay”

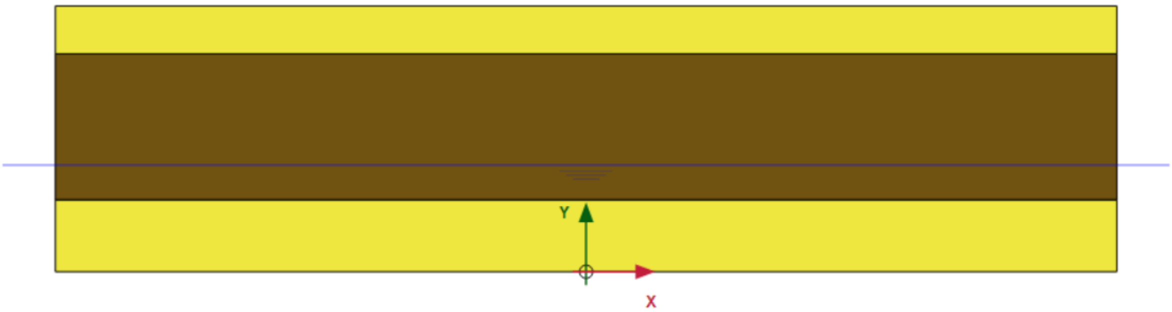


Fig. 5: The idealized geotechnical profile for the simulation

3 TEMPRARY SUPPORT SYSTEM SPECIFICATION

In order to limit pre-convergence displacement and avoid ground surface settlement in front of the excavation face in the Beaulieu metro station project; it has adopted a two types of support system and ground improvement.

- **Forepoling:** was performed using seamless pipes with the following specifications:

Table. 3: Temporary Support system specification

Designation	External diameter	Inner diameter
S355	88.9 mm	82.6

- **Jet grouting columns**

Concerning the ground improvement technique; it has been chosen the jet grouting columns that involves the creation of soil-cement columns through the injection of high-pressure jets of fluid into the soil. (See figure 6)

Table 4 presents minimum mechanical characteristics which must be evaluated by uniaxial compression tests.

Table. 4: Minimal Mechanical Characteristics

	fck min	fctk min	E min
Crown	5 MPa	1.1 MPa	1500 MPa
Invert	2.5 MPa	0.62 MPa	500 MPa

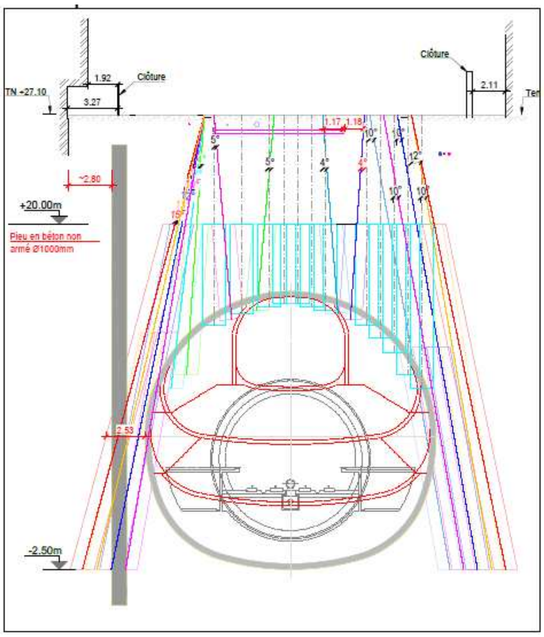


Fig. 6: layout of the jet grouting columns

- **Cut-off wall**

As a countermeasure to protect existing structures, it has been chosen a cutoff wall.

"Protection by an earth cutoff wall: is a method used to create a barrier between the cut-and-cover tunnel and existing structures to prevent propagation of displacement" (**STANDARD SPECIFICATIONS for tunneling 2016; cut and cover tunnels; JAPAN society of civil engineer**)

Therefore, a pile group was conceived between the western underground gallery and the nearby buildings which are vulnerable to strains caused by the underground excavation. (See Figure 35)

Table. 5: Cut off wall characteristics

Φ	**L (m)**	**Material**	**Round length (m)**
1000	30	Concrete	1.30

4 RESULTS OF THE WESTERN GALLERY PARAMETRS

4.1 *Model geometry*

Dimensions of the built models are considered to reduce boundary effects to minimum acceptable values. In this regard. The extent of the lateral and bottom boundaries in the 2D model was set equal to more than 5 times the tunnel radius.

Concerning loads: uniform loads of 11.11 KPa (machines…) and load of 77.70 KPa. (To take into account the effect of the nearby structures)

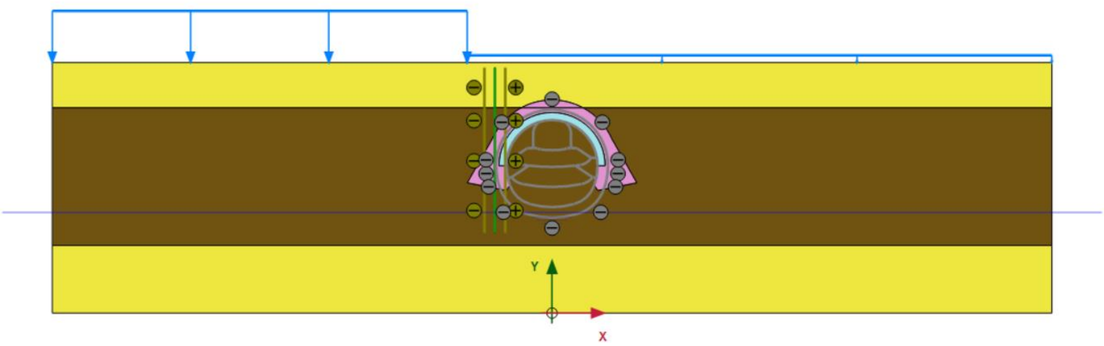


Fig. 7: Model geometry of the 2D gallery simulation

4.2 *Choice of soil model*

It said to be a realistic prediction of ground movements requires using the models which account for the complex soil behavior. This latter stems from the nature of the multiphase materiel which reveal both elastic and plastic non-linarites we opted for the hardening soil model; a highly recommended model when it comes to settlement and deformation prediction; because it is an elastoplastic hyperbolic type model, in which the yield surface increases in the form of strain hardening soil plasticity, and considers the stress history and differentiate between loading and unloading

Table. 6 : Choice of soil model Handout Plaxis Introduction, online course, Benltly.com

<table>
<tr><td colspan="2" rowspan="2"></td><td>SOFT SOILS
(NC- CLAY, PEAT)</td><td>HARD SOILS
(OC-CLAY, SAND, GRAVEL)</td></tr>
<tr><td colspan="2">RECOMMENDED MODEL</td></tr>
<tr><td colspan="2">PRIMARY LOADING (SURCHARGES)</td><td>SOFT SOIL (CREEP), HARDENING SOIL, HS SMALL</td><td>HARDENING SOIL, HSSMALL</td></tr>
<tr><td>UNLOADING WITH DEVIATORIC LOADING (EXCAVATIONS, TUNNELS)</td><td>HARDENING SOIL HSSMALL</td><td colspan="2">HARDENING SOIL, HSSMALL</td></tr>
<tr><td>DEVIATORIC LOADING</td><td>SOFT SOIL (CREEP) HARDENING SOIL, HS SMALL</td><td colspan="2">HARDENING SOIL, HSSMALL</td></tr>
<tr><td>SECONDARY COMPRESSION</td><td colspan="3">SOFT SOIL CREEP, CREEP-SCLAY1S</td></tr>
</table>

4.3 *HS parameters determination*

4.3.1 *Procedure*

a) Determine soil parameters based on given real laboratory OR FIELD test results case records
b) Calibrate the soil parameters set by performing the laboratory oedometer or/and a triaxle tests using **Soil Test** with the parameters found
c) Match Soil Test results with the original laboratory results to find the best matching model parameters for the Hardening Soil model.

4.3.2 *Summary of HS chosen parameters*

Table. 7: Summary of HS chosen parameters

Parameters	**Unit**	**Values**	
		SAND	**CLAY**
E50 ref	Kpa	45 000.00	4 728.24
Eoed ref	Kpa	45 000.00	2 364.12
Eur ref	Kpa	141 128.31	7 792.37
Pref	Kpa	100.00	100.00
ϑ'ur		0.20	0.20
C'	Kpa	42.00	81.67
ϕ'	°	15.00	15.10
ψ	°		0.00
m	-	0.50	1.00
K0 NC	-	0.74	0.74

4.4 *Support system Simulation*

4.4.1 *Initial Support system characteristics*

The initial support system were approximated as a material with an equivalent strength and represented as shell elements

Table. 8: Initial Support system characteristics

		EA (KN/m)	EI (KN*m2/m)	W (KN/m/m)	ν
Crown	HEB 140(1m) + BP 25(cm)	3.608×10^6	27513.9	3.75	0.2
Invert	HEB 200 (1m) + BP (35cm)	4.345×10^6	36306.6	5.25	0.2

4.4.2 *Temporary support system*

a) Forepoles (umbrella arch)

Three different approximations of the Umbrella Arch are identified from case histories and evaluated using the numerical modelling procedures.

1. Method (1) - Steel pipes, grout and rock material properties are combined using weighted averages and an equivalent rock mass strength is derived (Hoek, 2000).

2. Method (2) - Steel pipes are modelled using beam elements. Grout and rock material properties are combined using weighted averages and an equivalent rock mass strength is derived (Hefny et al., 2004).

3. Method (3) - Steel pipes are modelled using beam elements and grout is also modelled as beam elements around the tunnel periphery (Figure 4-2c) (Hefny et al., 2004).

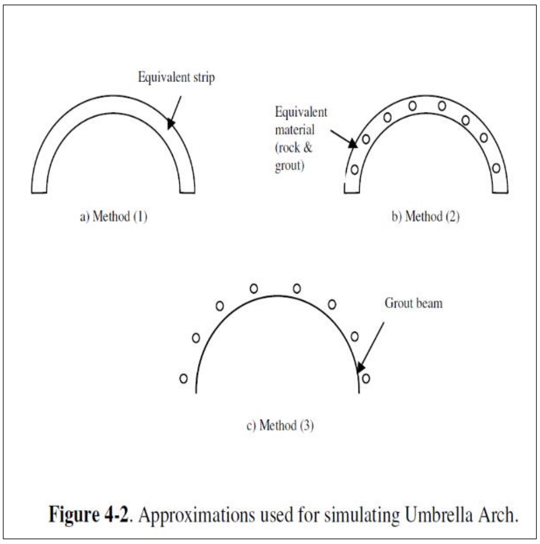


Fig. 8: Approximations used for simulating Umbrella Arch

➔We opted for the first method, which Evert **Hoeck** proposed to simulate the action of forepoling as a composite Beam (wide of 1m and depth= implementation depth of the forepoling)

Table. 9: Equivalent zone characteristics

	Module of elasticity E (KPa)	Cohesion C (KPa)	Friction angle ϕ (°)	Unit weight γ (KN/m^3)
Soil	1.70 E4	76	14.5	20
Steel pipe	2.10 E8	-	-	78
Grout	9.00 E6	-	-	24
Equivalent zone	**7.03 E4**	**760**	**14.5**	**20.02**

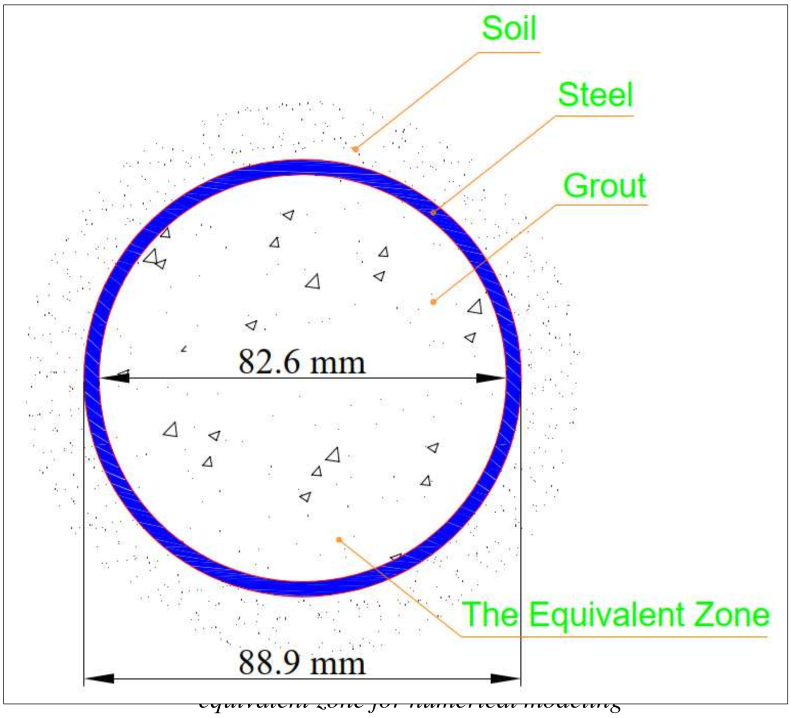
Cohesion of the forepoling equivalent zone is assumed 10 times the soil cohesion, and its internal friction angle is set equal to soil's friction angle.

b) Cut-off wall

It has been simulated as a plate element with the following characteristics

Table. 10: Cut-off wall characteristics

EA (KN/m)	**EI (KNm2/m)**	**w**	**ν**
19.94	1.25 E6	3.02	



equivalent zone for numerical modeling

c) Reinforcement (ground improvement) "Jet grouting effect"

There is a three different methods to simulate the effect of jet grouting columns during FEM analyses. (Barla Marco & Joannna Bzowka)

Method A: jet grouting columns are simulated by applying the correspondent material properties to the finite elements belonging to the reinforced arch at the crown.

Method B: the jet-grouting umbrella is simulated by accounting for the original circular geometry of each column.

Method C: the jet-grouting umbrella effect is simulated by introducing a structural interface (a standard beam plus two joints). The geometry of the umbrella is not properly reproduced as its thickness is not considered

We opted for the first method and the properties of the jet grouting are presented in the following table.

Table. 11: jet grouting parameters

Weight (KN/m^3)	**Su (KPa)**	**E(MPa)**	ϑ
23	2000.00	400	0.2

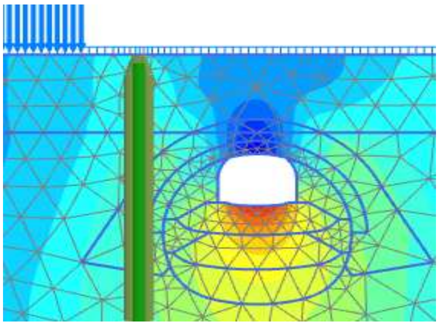
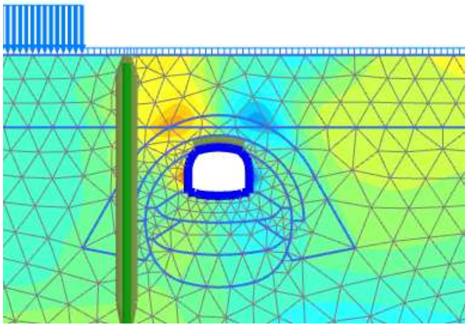
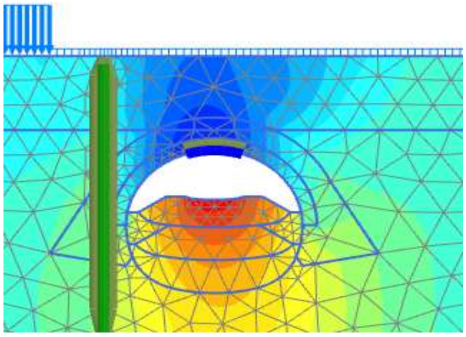
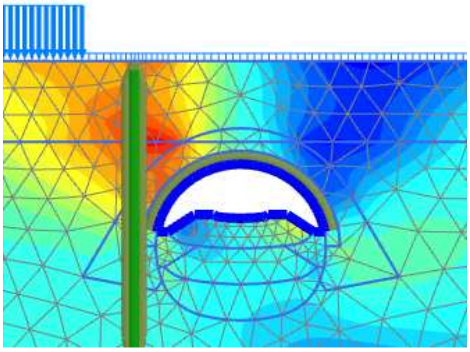
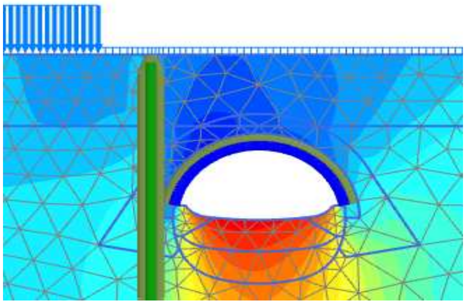
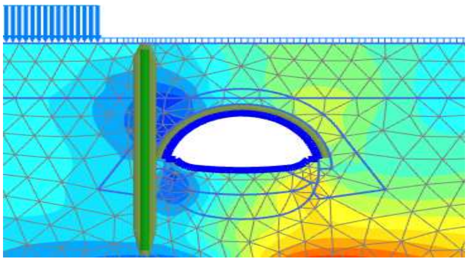
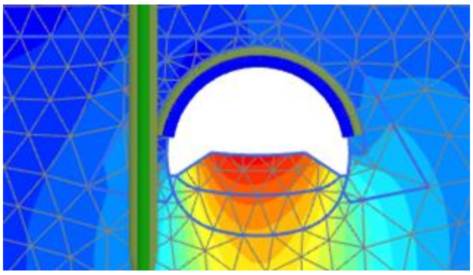
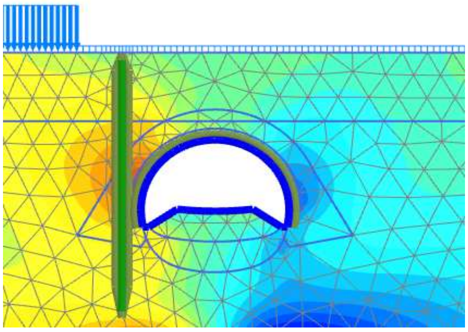
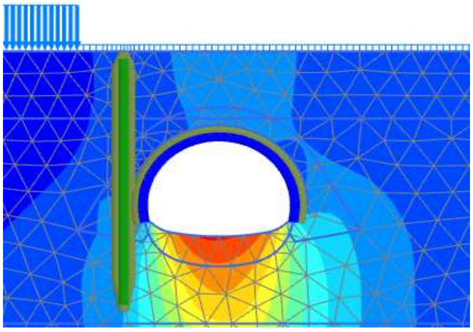
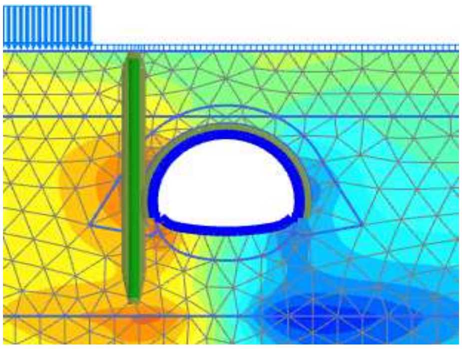
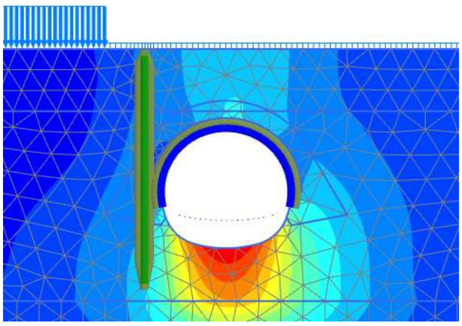
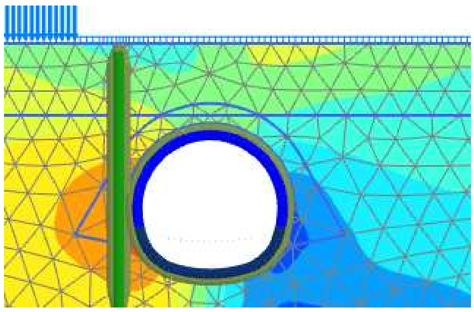
5 RESULTS OF THE WESTERN GALLERY 2D SIMULATION

- ### Excavations stages

Phase 1: Initial stress development due to soil weight,
Phase 2: Application of surface loads. The displacements are set to zero at the end of this stage,
Phase 3: Activation of forepoling zone, cut off-wall and jet grouting zone,
Phase 4: Excavation of top heading,
Phase 5: Installation of initial support system,
Phase 6: Excavation of the two remainder of headings,
Phase 7: Installation of support system for second side drift,
Phase 8: Excavation of the 1st Bench,
Phase 9: Installation of 1st Bench support system,
Phase 10: Excavation of the side drifts,
Phase 11: Installation of side drifts lining,
Phase 12: Excavation of the 2nd bench,
Phase 13: Installation of the 2nd bench lining
Phase 14: Excavation of 3rd bench
Phase 15: Installation of the 3rd bench lining (Invert)

- ### Plaxis output

This section shows the results of a 2D plane strain model for the western gallery

Phase 4	Phase 5	Phase 6
		
Phase 7	Phase 8	Phase 9
		
Phase 10	Phase 11	Phase 12
		
Phase 13	Phase 14	Phase 15
		

- **Influence of support system type on displacement**

The pictures below represents the influence of support system type on horizontal and vertical displacement.

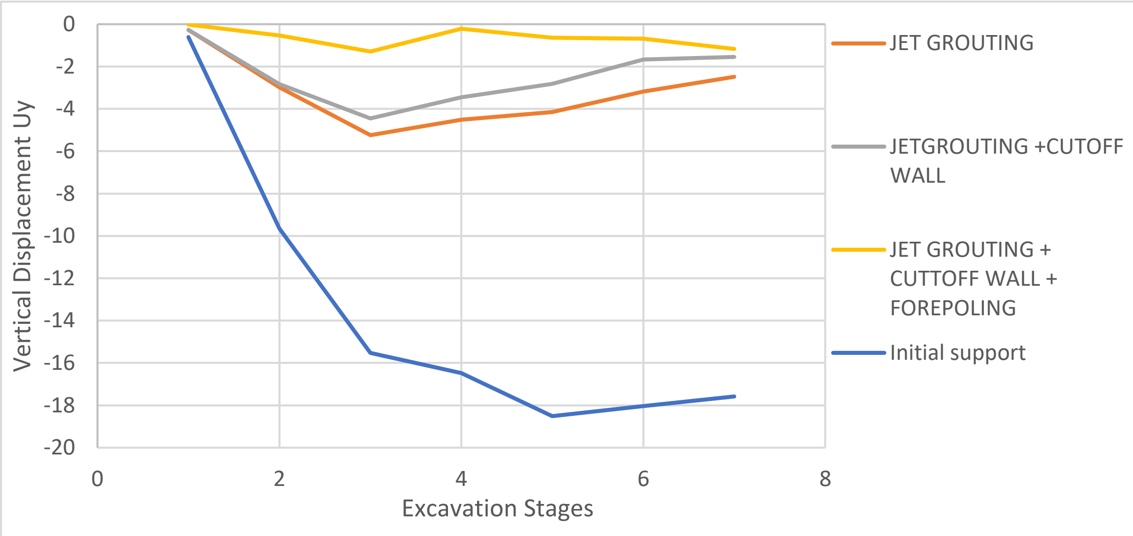


Fig. 10 : Variation of the vertical displacement according to the type of support system

In general; it can be seen that the horizontal displacement increases with excavation advance. when we set only the initial support, we noticed that the displacement reaches high values, and once we improve the ground, the displacement either the horizontal or the vertical decreases slightly and keep decreasing each time we add temprary support : cuttoff wall and forepolling

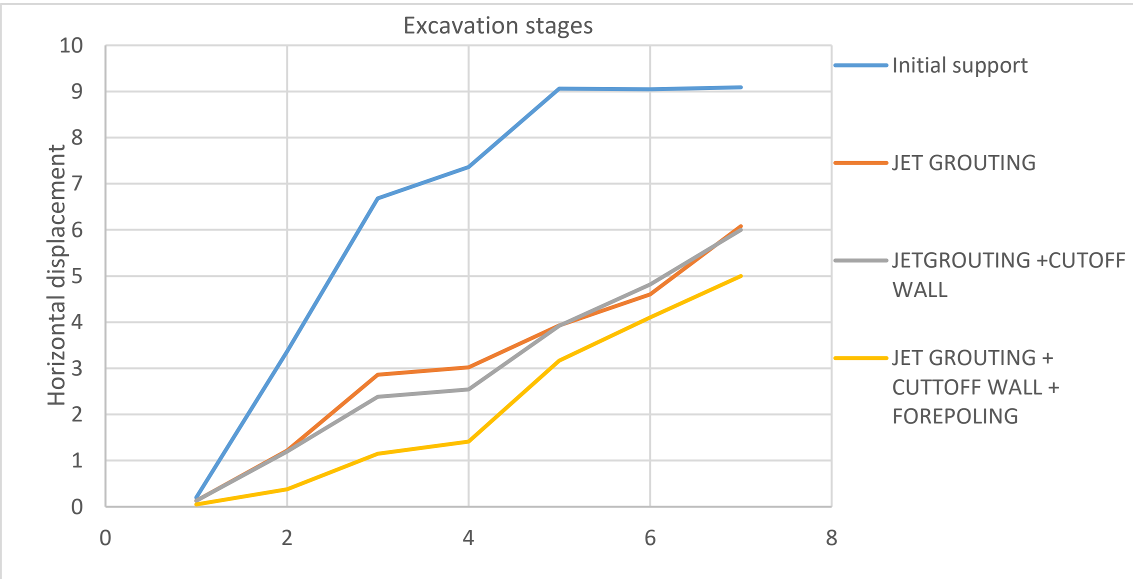


Fig. 11 : Variation of the horizontal displacement according to the type of support system

6 ANALYSIS OF MONITORED DATA

The measurement started on 23th October at the same time as the beginning of the excavation, but the excavation finished on June 16th 2022.
When the tunnel face was excavated, the settlement increased quickly (phase 1). About half a month later, the settlement continued to increase but with a relatively smaller increase rate (phase 2). The settlement eventually increased up to ~ 7 mm and stabilized about 3 months after.

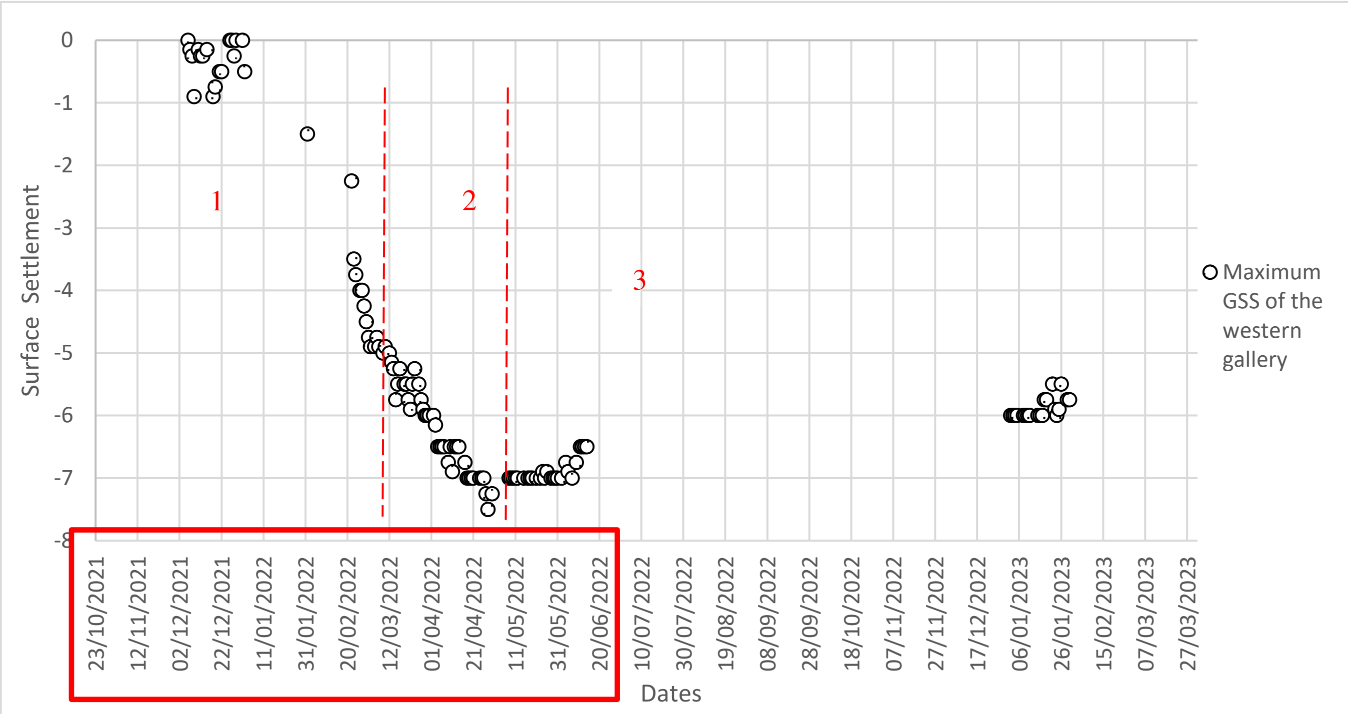


Fig. 12 : Date-Settlement curve of the western Gallery

Reappearance of settlement after six (06) months of finishing excavation may be caused by the TBM which passed after the complete construction of the gallery.

➔One can noticed significant difference between the numerical ground surface settlement values and those of instrumentation.

7 CONCLUSIONS

Based on the current research, the main findings can be summarized as below:

1. The combination of ground improvement + initial support + temporary support have the highest effect in reducing excavation face deformation and thus ground surface.
2. Initial support system is incapable to withstand the displacement alone.
3. The forepolling umbrella system; thanks to the reinforced arcuate zone; provides protection at the excavation face in both longitudinal a transversal direction of the tunnel.
4. Ground improvement (jet grouting columns) couldn't reduce the displacement and thus protect the surrounding building. On the other hand, the cut-off wall provides a significant limitation of Uy: vertical displacement.
5. Compared to the maximum ground surface settlement reached in field (from the monitored data) it can be noticed that 2D numerical analysis is not deemed adequate. Due to the influence of other structure excavation (for instance shaft) on the excavation of the western gallery.
6. 3D analysis is suggested to take into account the interaction between the different structures.

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Plaxis 2D tutorials

F. Tschuchnigg, H. F. Schweiger
Comparison of Different Models for Analysing Foundations on Jet Grout Columns
Computational Geotechnics Group, Institute for Soil Mechanics and Foundation Engineering, Graz University of Technology, Graz, Austria (Conferences paper : The 12th International Conference of *International Association for Computer Methods and Advances in Geomechanics (IACMAG)*1-6 October, 2008 Goa, India)