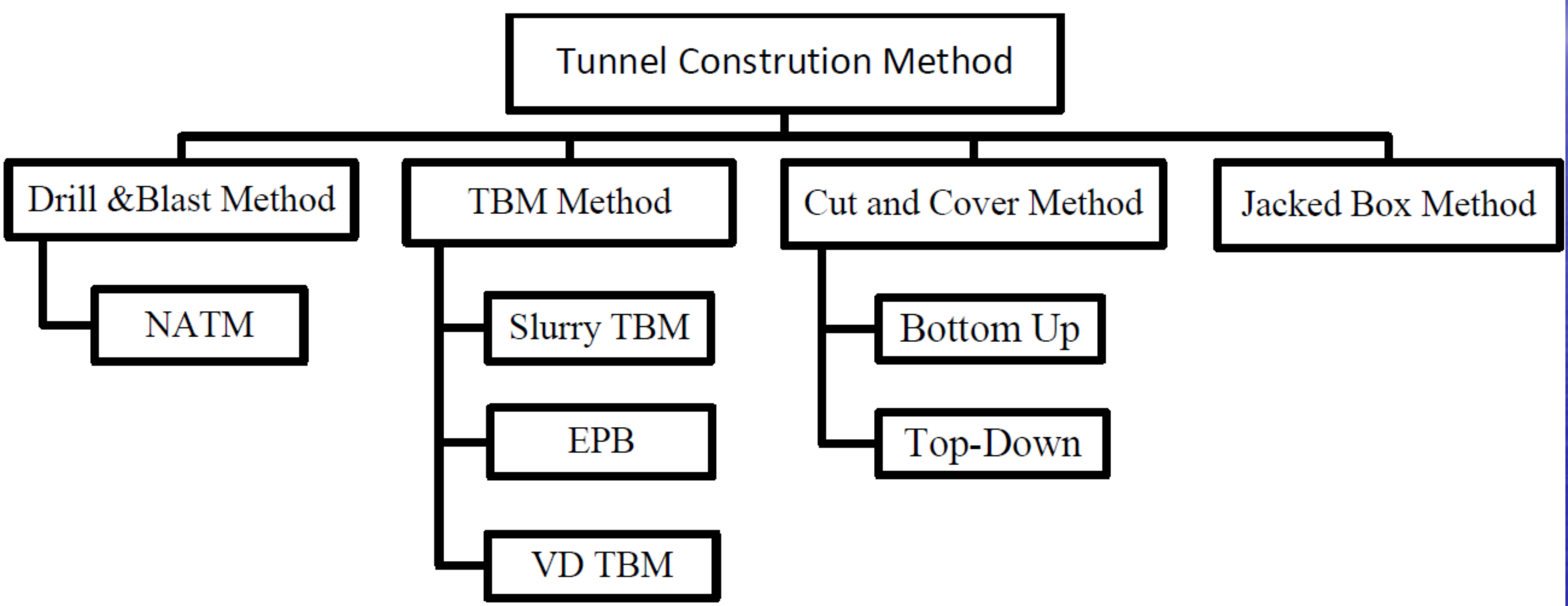
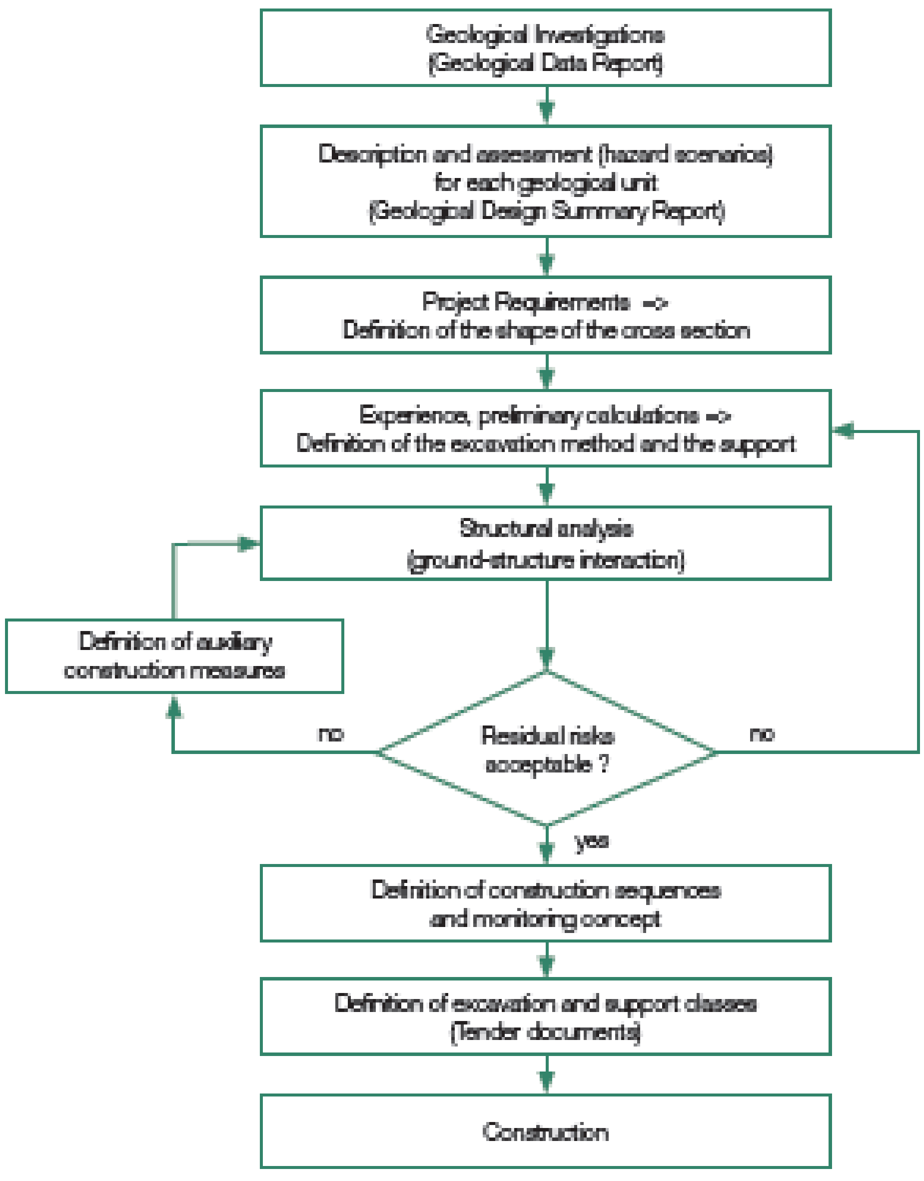
Túneis NATM e TBM

da Prospecção Geológico Geotécnica
à
Escavação e Revestimento


Tunnel Constrution Method
Drill &Blast Method
TBM Method
Cut and Cover Method
Jacked Box Method
NATM
Slurry TBM
EPB
VD TBM
Bottom Up
Top-Down

NATM



Design steps for conventional tunneling

NATM

Key features of the NATM design philosophy are:

- The strength of the ground around a tunnel is deliberately mobilized to the maximum extent possible.
- Mobilization of ground strength is achieved by allowing controlled deformation of the ground.
- Initial primary support is installed having load-deformation characteristics appropriate to the ground conditions, and installation is timed with respect to ground deformations.
- Instrumentation is installed to monitor deformations in the initial support system, as well as to form the basis of varying the initial support design and the sequence of excavation.

Key features of NATM construction methods are:

- The tunnel is sequentially excavated and supported, and the excavation sequences can be adjusted.
- The initial ground support is provided by shotcrete in combination with fiber or welded-wire fabric reinforcement, steel arches or lattice girders, and sometimes ground reinforcement (e.g., soil nails, spiling).
- Membrane based waterproofing system sandwiched between initial and final lining.
- The permanent support is usually (but not always) a cast-in-place concrete lining.

NATM

In practice, the NATM combines ground conditions, excavation procedure, and tunnel support requirements. It is basically a 'build as you go' approach based on monitoring, backed by theoretical considerations.

As defined by the Austrian Society of Engineers and Architects, the NATM "…constitutes a method where the surrounding rock or soil formations of a tunnel are integrated into an over-all ring-like support structure. Thus the supporting formations will themselves be part of this supporting structure." In world-wide practice, however, when shotcrete is proposed for initial ground support of an open-face tunnel, it is often referred to as NATM, even though the methods do not always follow the general principles of NATM.

NATM

NATM / SCL / SEM

The New Austrian Tunnelling Method (NATM) is also known as Sprayed Concrete Lining (SCL) or Sequential Excavation Method (SEM). NATM involves lining the walls of an excavated tunnel with wire mesh, then spraying them with quick-drying concrete. A second concrete lining can be installed later.

NATM was developed between 1957 and 1965 in Austria. The main idea is to use the geological stress of the surrounding soil mass to stabilize the tunnel itself.

Advantages

- Eliminates the need for using some expensive TBM equipment during excavation
- Suitable for a wide range of geometry (shafts, junctions, non-circular tunnels and tunnels with variable shapes)

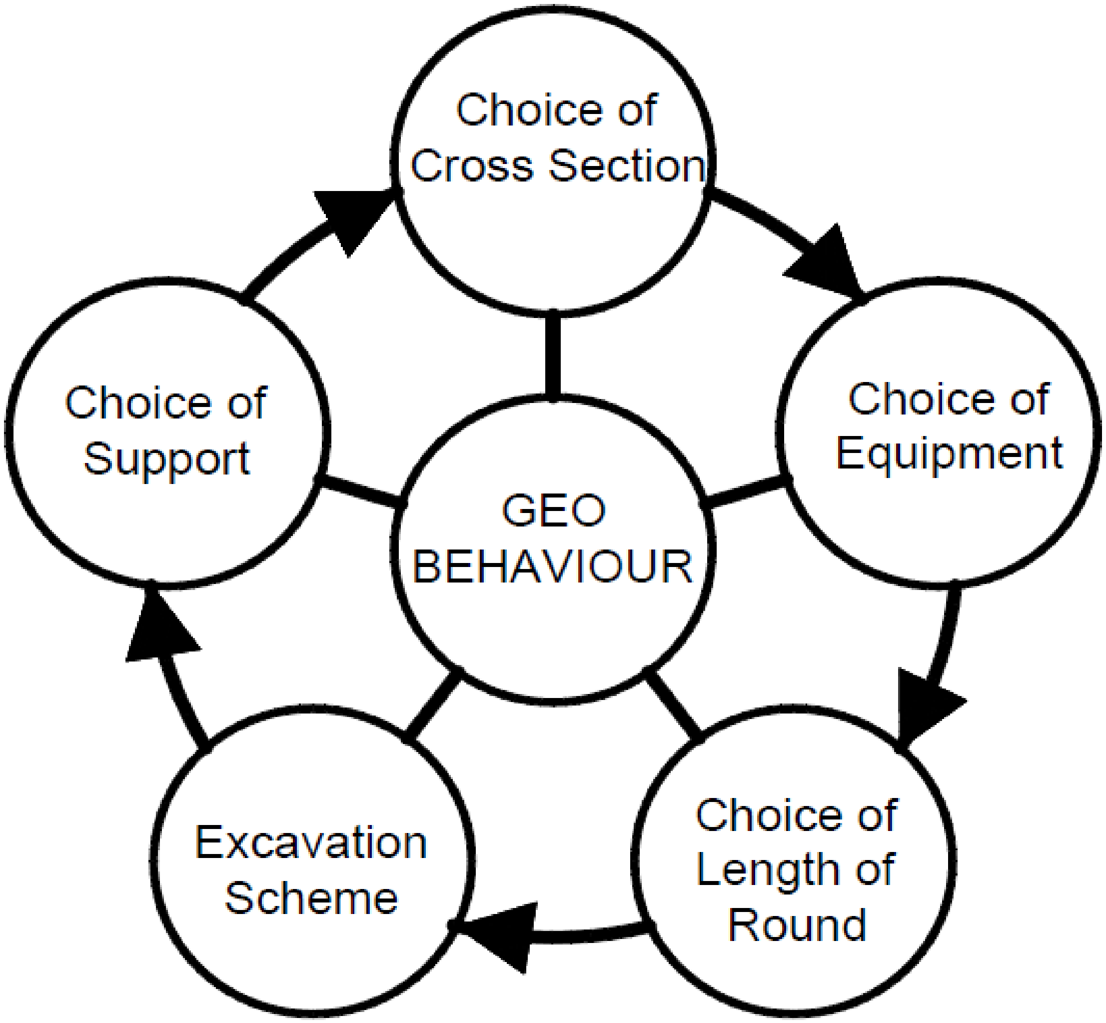
Disadvantages

- Its suitability diminishes in softer ground, which can subside when excavated
- Not suitable below water table in highly permeable soils

Main characteristics

- Tunnel Lining – Sprayed Concrete
- Typical Performance - 1m to 3m per day. Actual performance and costs will depend on ground conditions and tunnel diameter
- Typical Costs – USD 9,700 to USD 88,525 per metre

4.6 INTERDEPENDENT CHOICES IN CONSTRUCTION



Ground Behaviour determines need for Ground Support

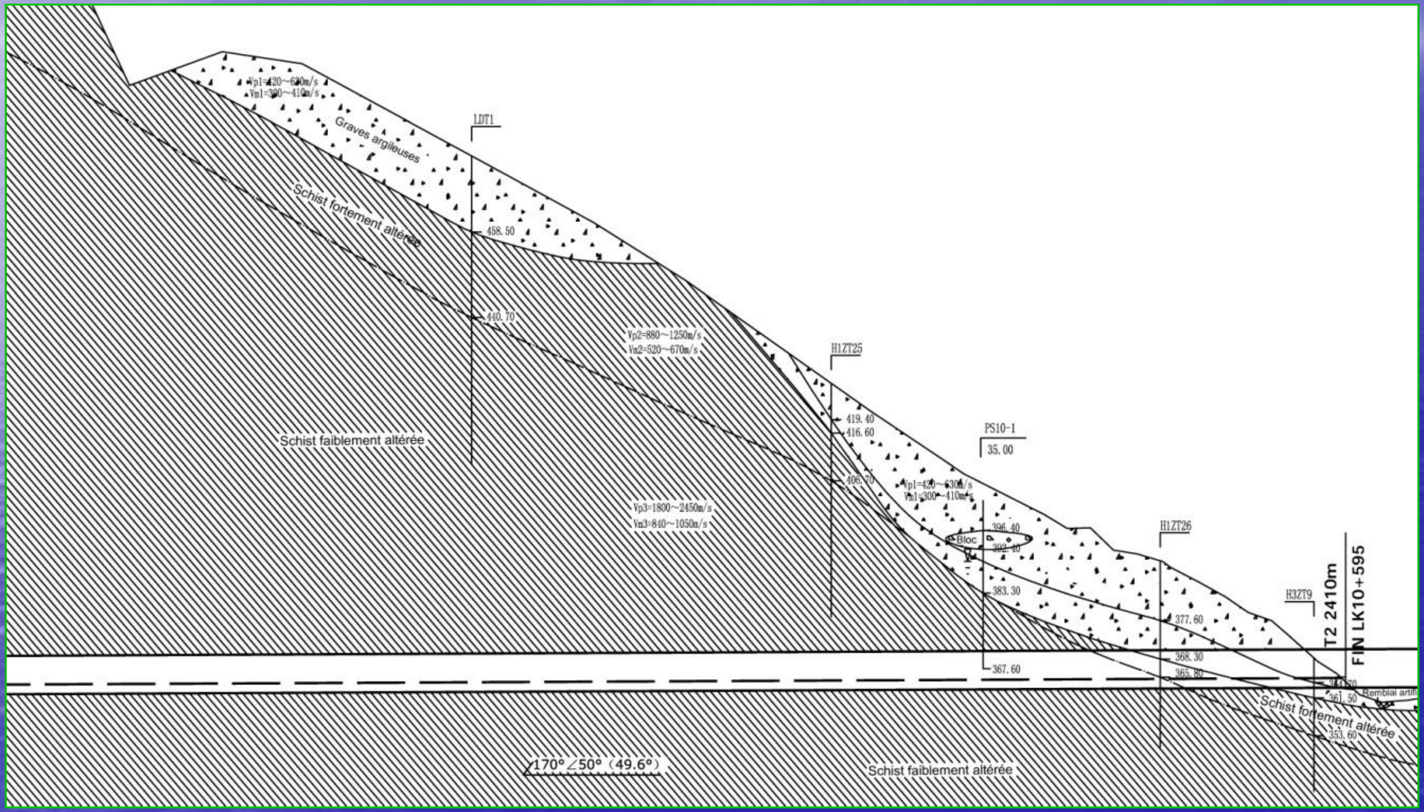
Agence Nationale des Autoroutes

Direction régionale centre

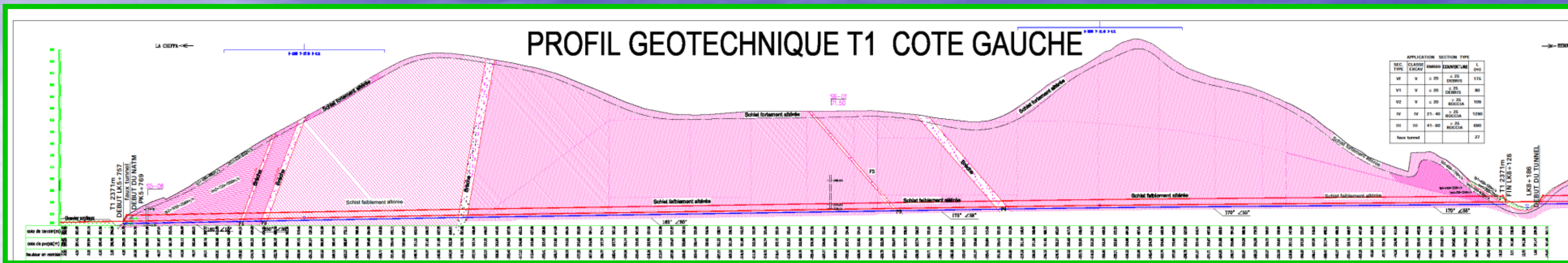
Autoestrada entre Chiffa e Berrouaghia - 53 Km

Tuneis

Dificuldades de Prospecção em Zonas Montanhosas -Topografia

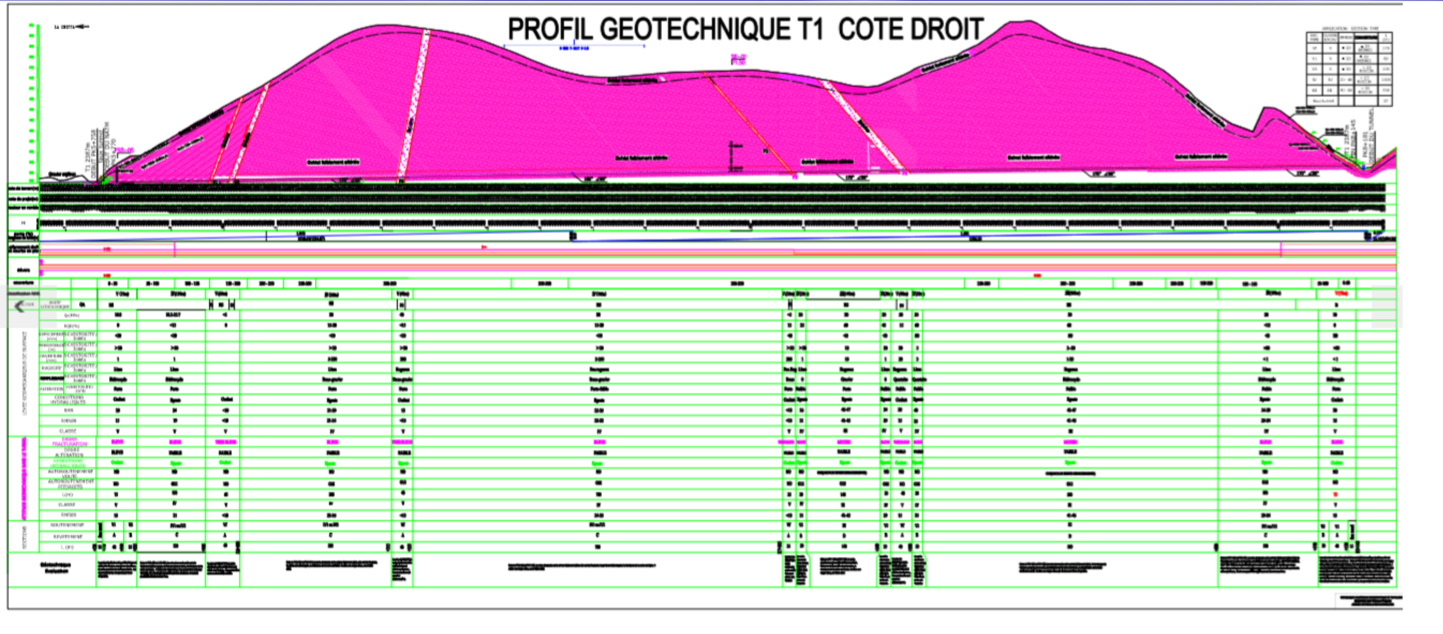


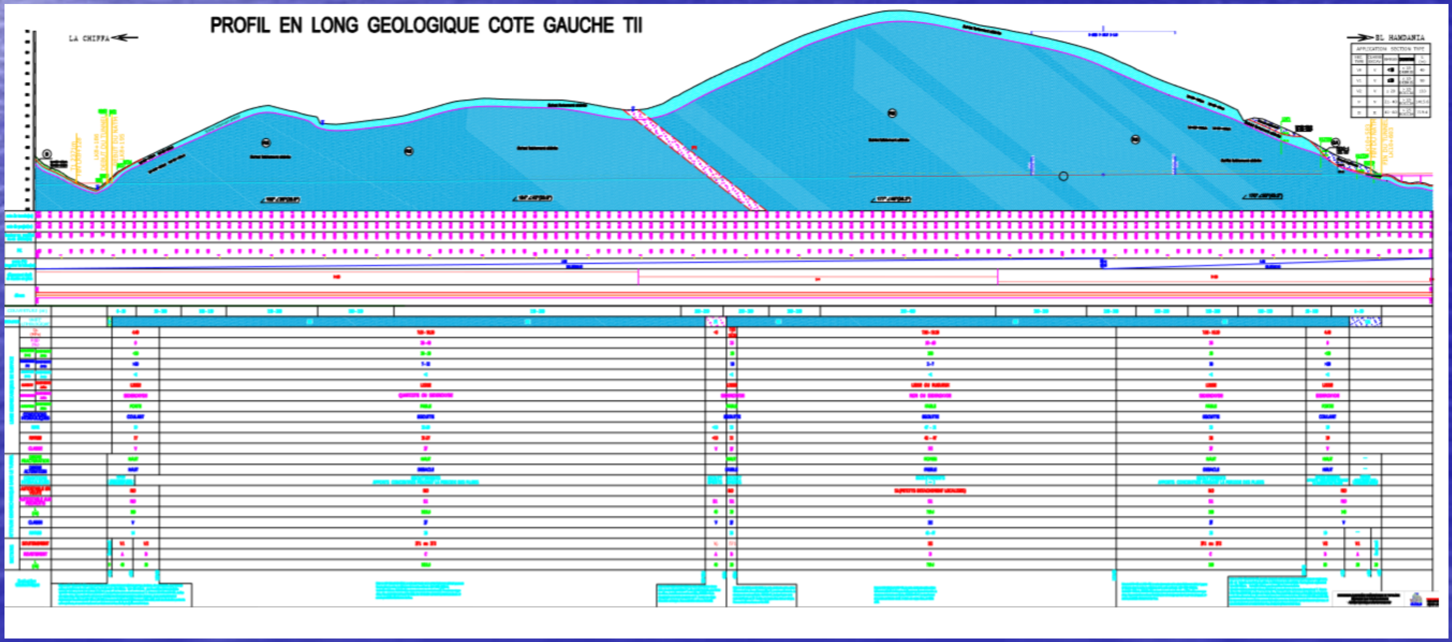
Litologia e Características Geomecânicas



paramètres / Lithologie	RMR	ρ h(g/cm^3)	C (kPa)	φ (°)	ν	E (GPa)	Classe d'excavation
Bloc	V	2.30	5	38	0.38	0.3	II
Brèche	V	2.20	120	22	0.38	0.5	II
Schiste fortement altérée	V	2.20	120	22	0.38	1.0	I - II
Schiste faiblement altérée	IV	2.40	200	28	0.32	2.0	III
Schiste faiblement altérée	III	2.50	250	35	0.28	5.0	III

Caracterização Geológico Geotécnica



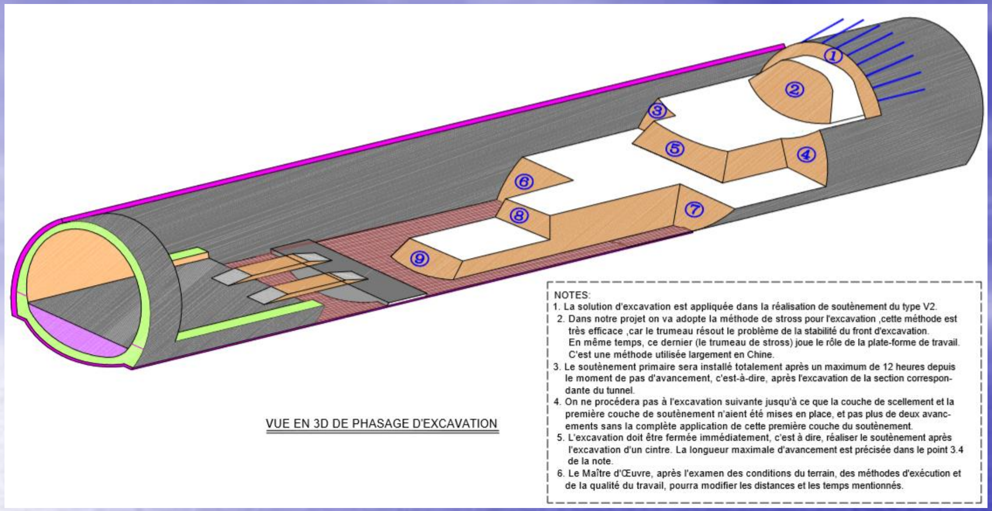


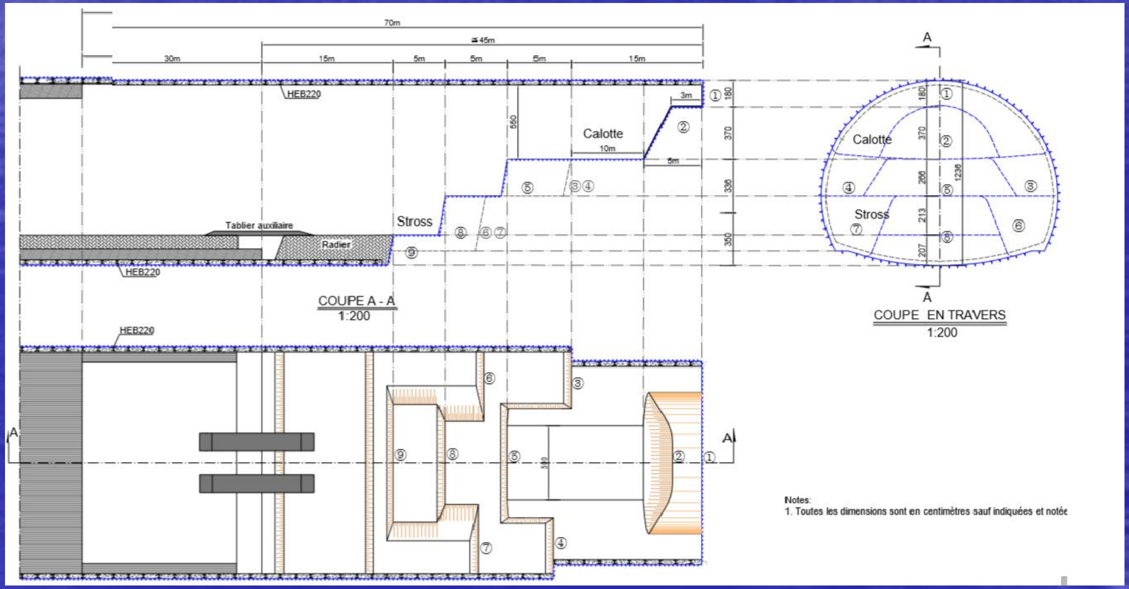
Classe de Terreno - Tipos de Sustimento

Indice RMR			<20		21~40		41~60	>61
			<11	11~20	21~30	31~40	41~60	>61
Classe du terrain encaissant			V1	V2	IV1	IV2	III	II
Evaluation de la condition géologique			Très mauvaise (la couverture de tête du tunnel est faible)	Très mauvaise	Médiocre	mauvaise	Passable	Bien
Type de soutènement			V1	V2	IV1	IV2	III	II
Soutènement	Les tolérances de convergence		15cm	10cm	7cm	7cm	5cm	3cm
Soutènement	Béton projeté RN30		30cm	28cm	24cm	20	20cm	10cm
Soutènement	Treillis soudes 15cm×15cm		15cm×15cm Bicouche	15cm×15cm Bicouche	15cm×15cm Bicouche	15cm×15cm couche simple	15cm×15cm couche simple	15cm×15cm couche simple
Soutènement	Cintres	HEB/ cintres réticué	HEB220	HEB220	HEB180	HEB140	HEB140	
Soutènement	Cintres	Écartement	0.8±0.2m	1.0±0.2m	1.0±0.2m	1.0±0.2m	1.25±0.25m	
Soutènement	tirant d'ancrage vertical au sol encaissant	Type de tirant radiale	Tube φ42	HA25	HA25	HA25	HA25	HA25
Soutènement	tirant d'ancrage vertical au sol encaissant	Longueur (m)	4m(Optionnelle) (150cm×100cm)	4m(Optionnelle) 150cm×100cm	4m(Optionnelle) 150cm×100cm	4m(Optionnelle) 150cm×100cm	3m(Optionnelle) 150cm×120cm	3m (Optionnelle)
Soutènement	Pre-soutènement	Type	Tube d'injection φ42	Tube d'injection φ42	Tube d'injection φ42 (Optionnelle)	HA25 (Optionnelle)	-	-
Soutènement	Pre-soutènement	L (m)	L=4m	L=4m	L=4m	L=4m	-	-
Soutènement	Pre-soutènement	Espacement	0.40m transversal 1.6m longitudinal	0.40m transversal 2m longitudinal	0.45m transversal 2m longitudinal	0.5m transversal 2m longitudinal		
Soutènement	Micropieu		Pieu en tube acier Φ76 L=6m	-	-	-	-	-
Soutènement	S'il y a le radier		Oui	Oui	Oui	Oui	Non	Non
Soutènement	S'il y a des cintres prévus pour le radier		Oui	Oui	Non	Non	Non	Non

Escavação Classe de Terreno V2

11<RMR<20

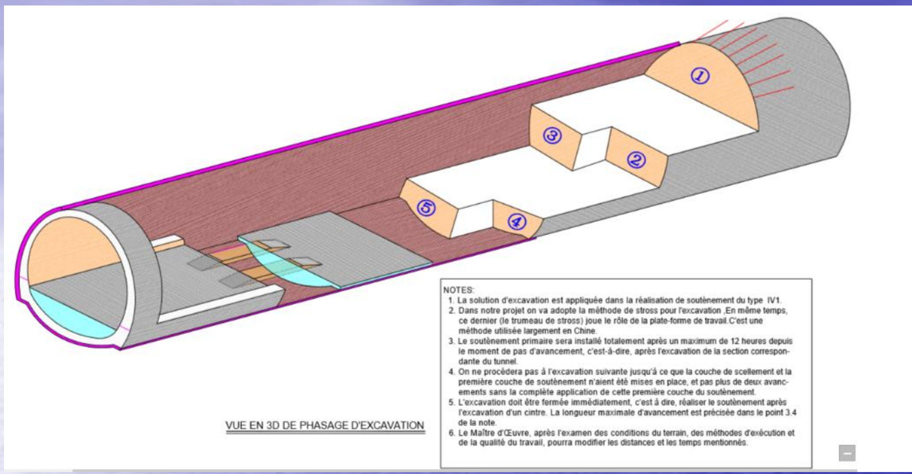


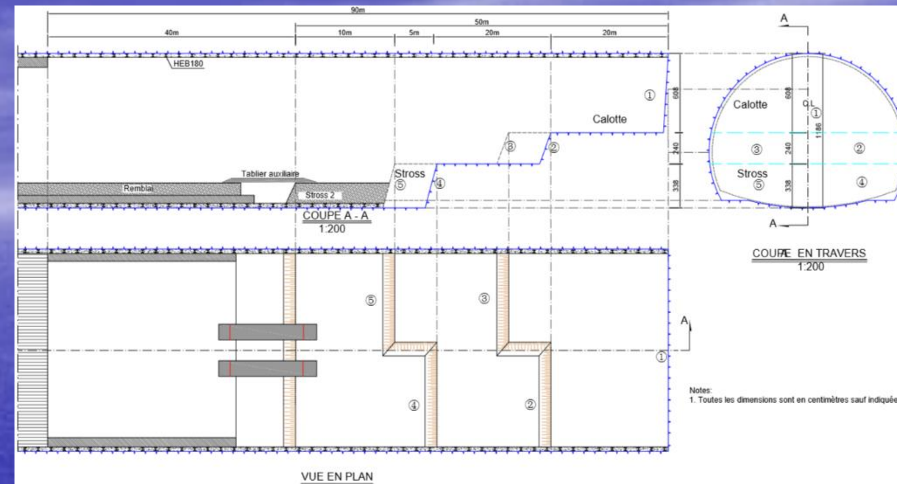


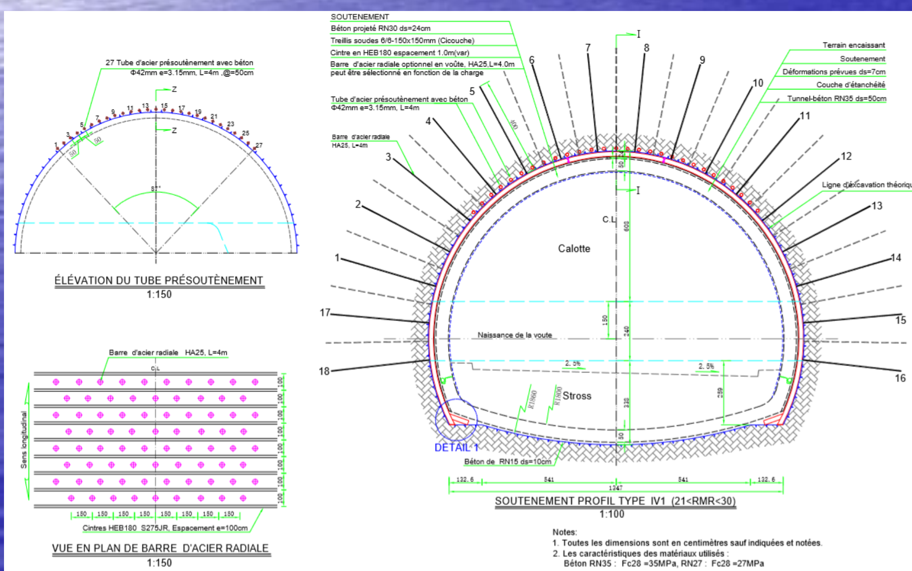
Escavação Classe de Terreno V2

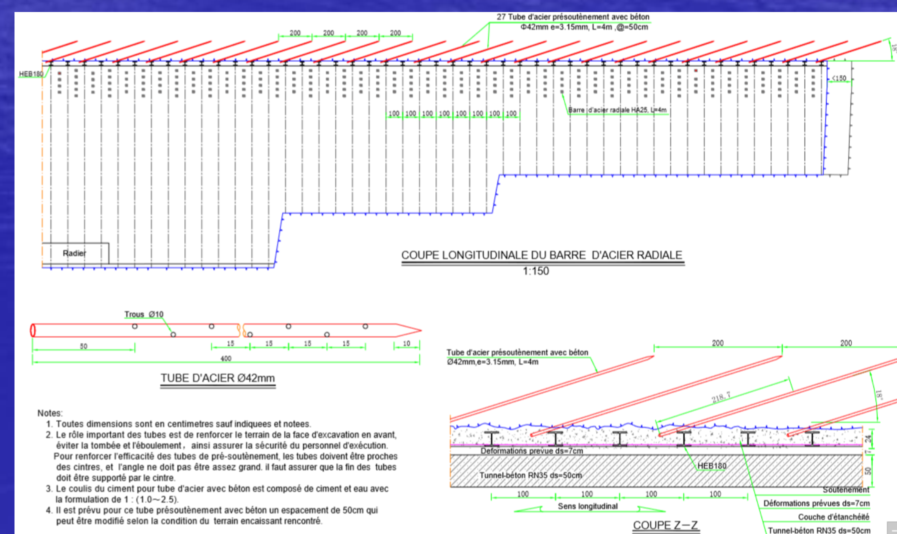
11<RMR<20

Escavação Classe de Terreno IV 1
21<RMR<30

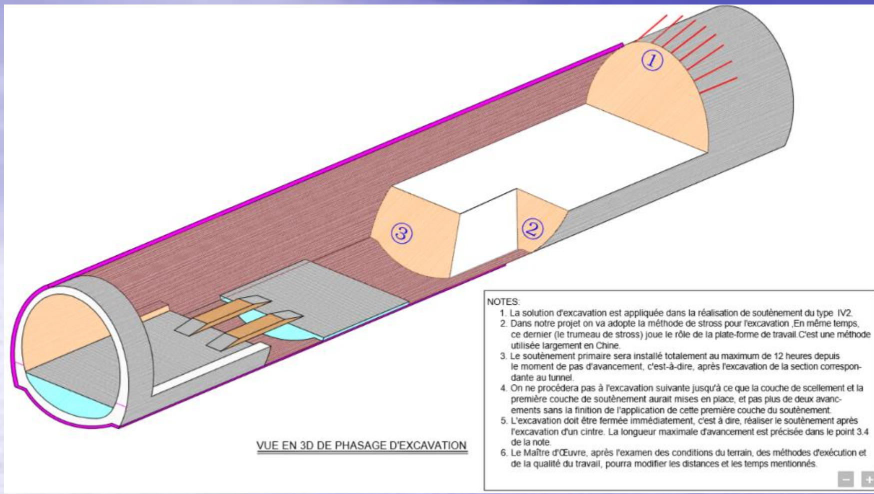


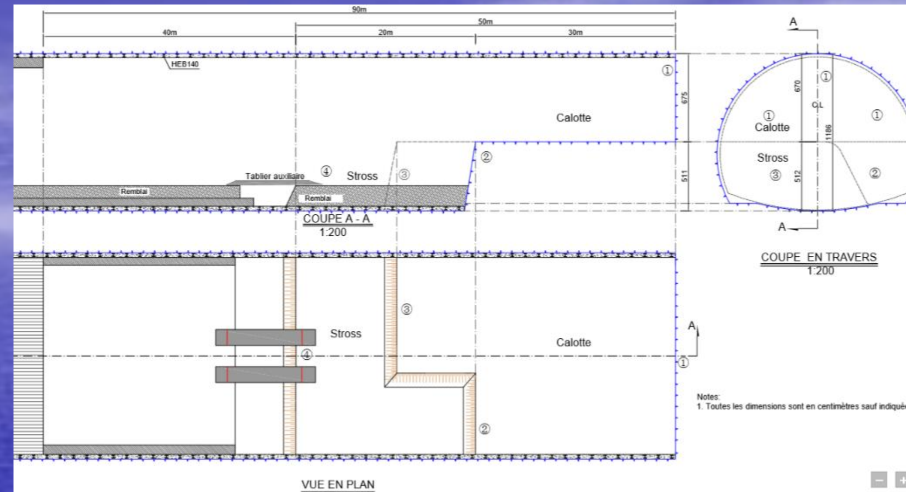


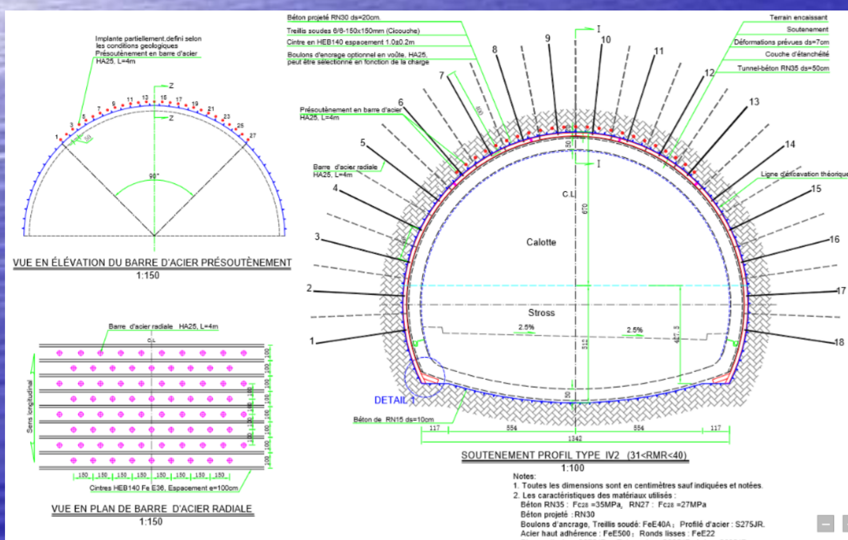


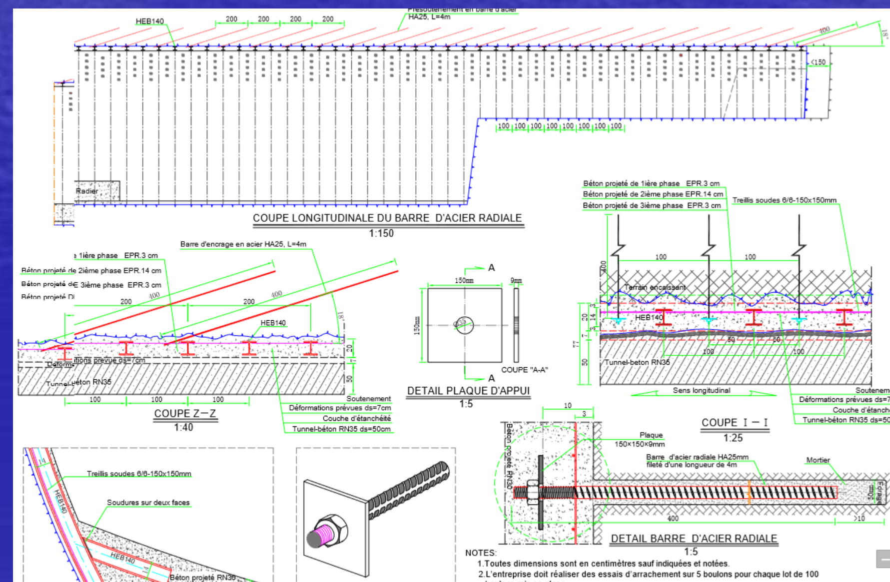


Escavação Classe de Terreno IV 2
31<RMR<40



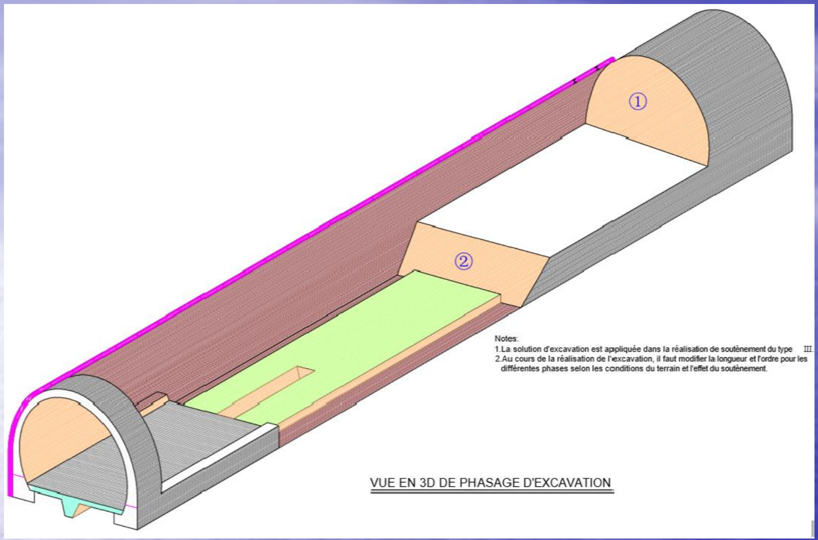


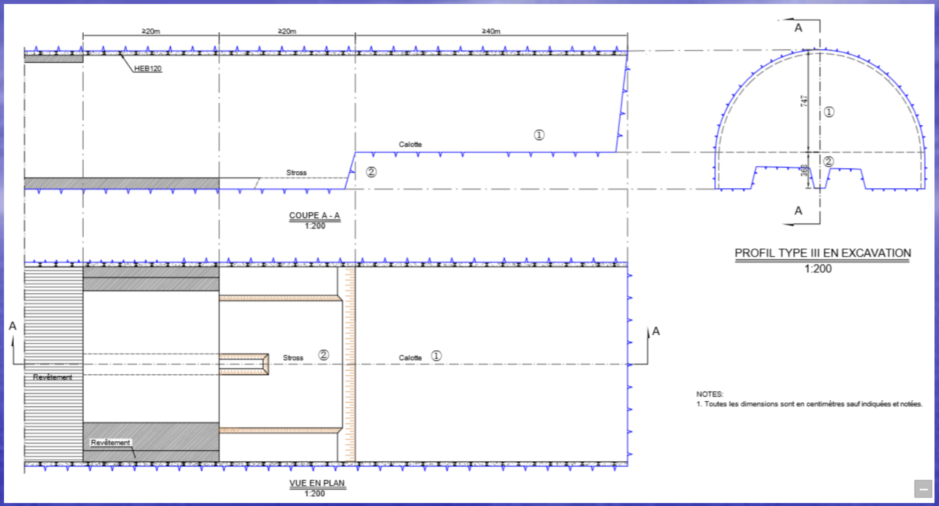


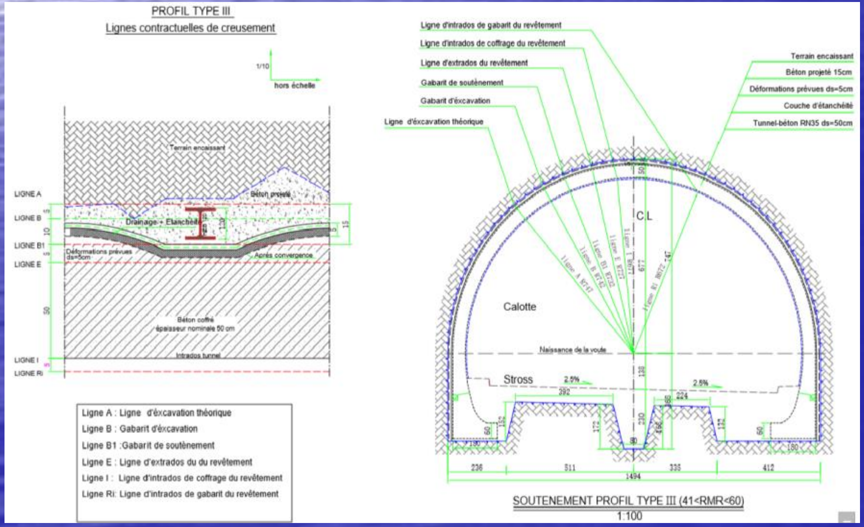


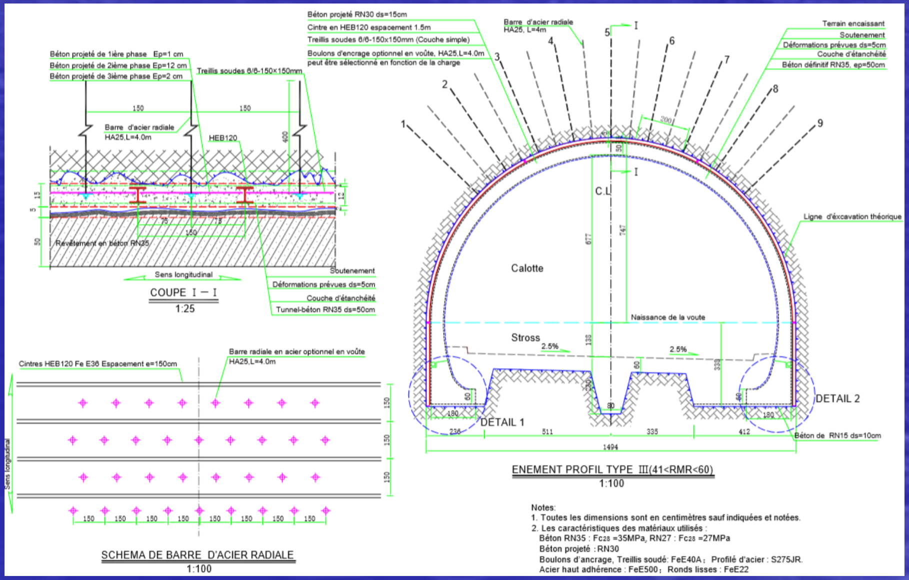
Escavação Classe de Terreno IV 2
31<RMR<40

Escavação Classe de Terreno III
41<RMR<60









Escavação Classe de Terreno III

41<RMR<60

Explosivo - Desmonte Calote

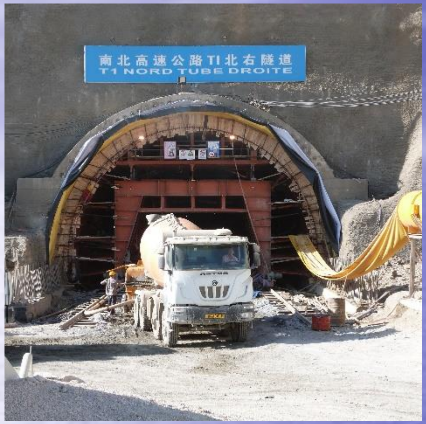
Ataque Pontual –Martelo Pneumático – Desmonte da Soleira

Revestimento Primário – Betão projectado

Revestimento Definitivo - Soleira

Impermeabilização

Revestimento Definitivo - Abóbada

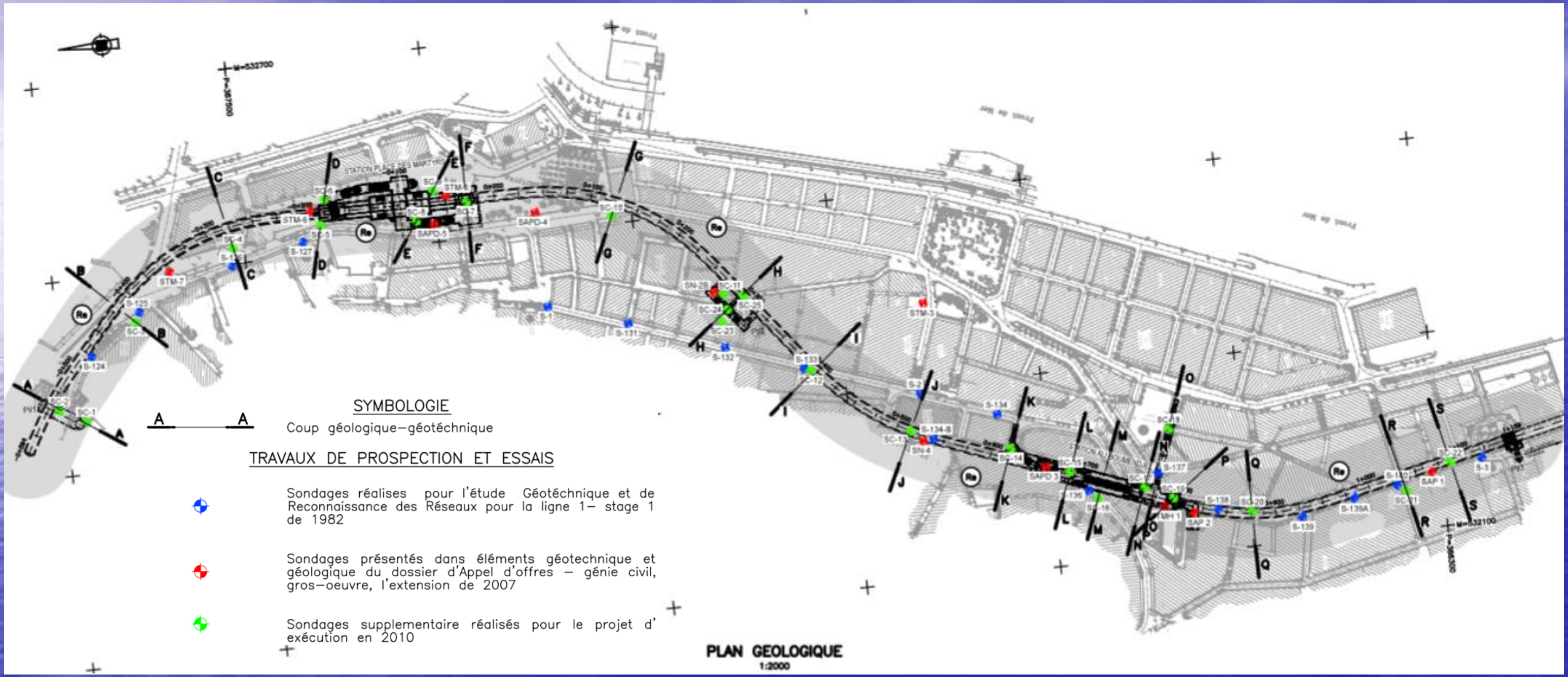


Metro d'Alger: Ligne 1 – Lot 1 – Extension A

Características Gerais do Projecto

- Extensão total de 1750m (em subterrâneo)
- 2 Estações e respectivos acessos (Praça dos Mártires e Ali Boumendjel)
- 3 Poços de ventilação (PV1, PV2 e PV3)

Prospecção Geológico Geotécnica – Localização de Sondagens



Zonamento Geotécnico

- Coberturas de aterros recentes (até 8m)
- Camadas aluvionares (até 7m)
- Maciço predominantemente constituído por xistos e localmente por níveis de calcário

W_5
σ_{ci} = 5 MPa
GSI = 10

CR3

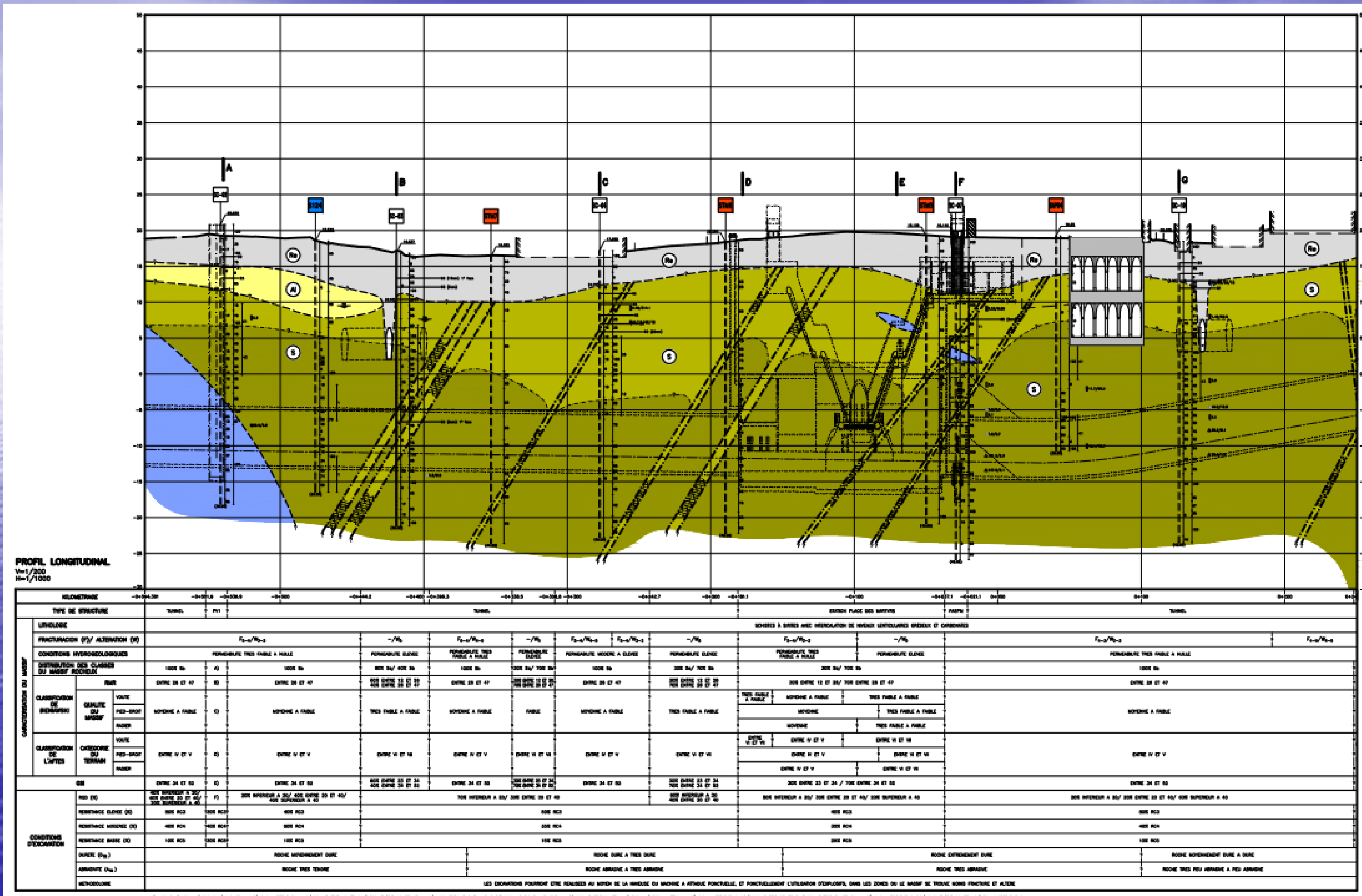
$W_{4\text{-}5}$
F_5
σ_{ci} = 15 a 30 MPa
GSI = 23 a 24

CR2

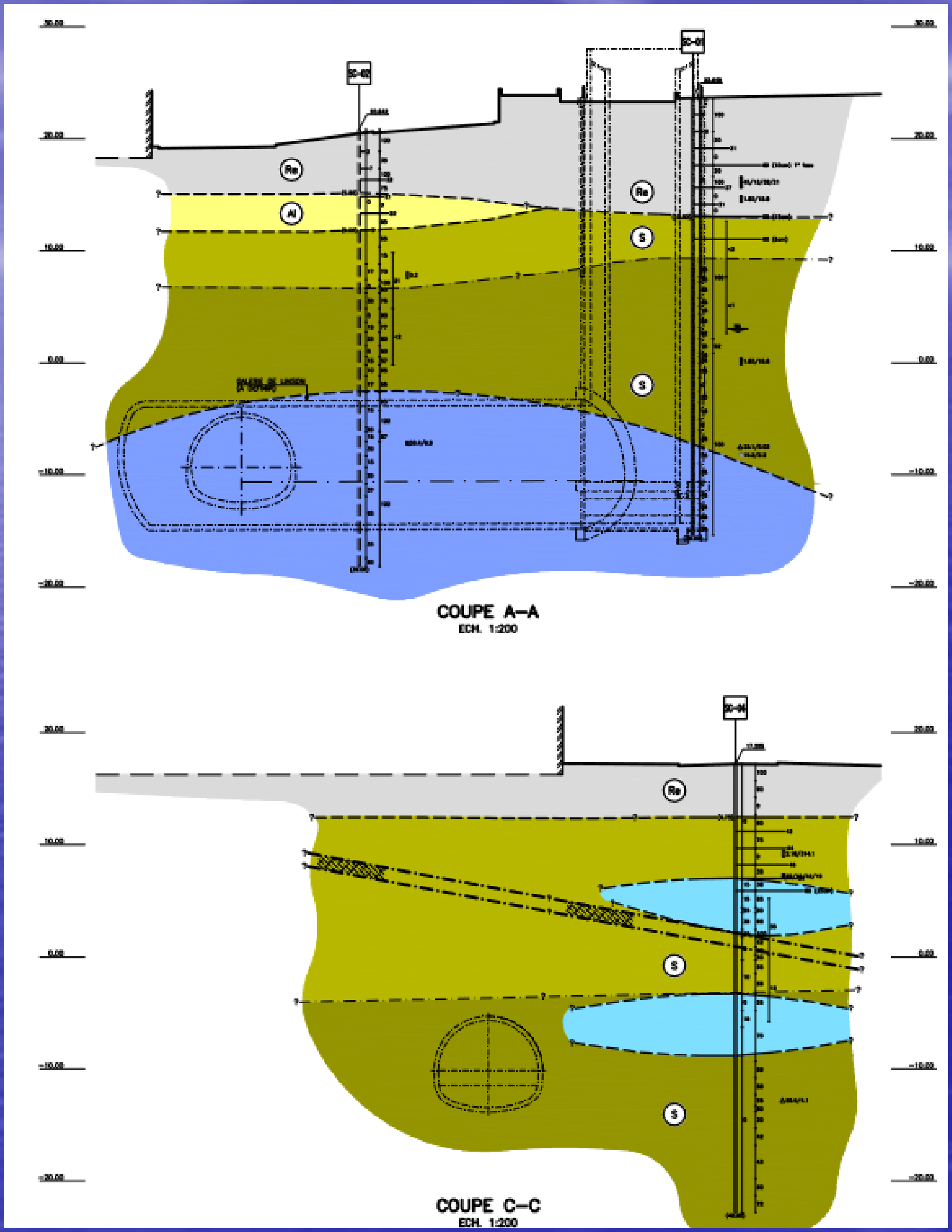
W_3
$F_{4\text{-}3}$
σ_{ci} = 40 a 80 MPa
GSI = 34 a 52

CR1

NATM: Zonamento Geotécnico – Perfil Longitudinal



NATM: Zonamento Geotécnico – Perfis Transversais



Características Litológicas e Geomecânicas dos Xistos

Complexes	Type lithologique		Structure						Caractéristiques mécanique de la Roche		Classification géo-mécanique	
	Description	Alter. (W)	Fract. (F)	R (%)	RQD (%)	N_{SPT}	Perméab.	Caractéristiq. des diaclases	σ_c (MPa)	E (GPa)	Bieniawski (1974, 1983 et 1989)	AFTES (1976, 2003)
S	Schistes altérés à décomposés et très fracturés, présentant fréquemment des intercalations de niveaux argileux avec des petits fragments de schistes épars, de couleur châtain-jaune (Sa)	W_{4-5}	F_5	0-100	0-40	8-60	Perméable en grand	Peu rugueuses à lisses, ouverture entre 1 et >5 mm, parfois de remplissages, avec des vestiges de circulation d'eau	15-30	-	Classe IV-V Mauvaise à très mauvaise	Catégorie VI-VII Roches de faible résistance à sols très consolidés
	Schistes, moyennement altérés a peu altérés, et de fractures moyennement écartées a proches (Sb)	W_{3-2}	F_{4-3}	20-100	0-90	-	Basse à variable	Légèrement rugueuses, ouverture entre 0,1 et 5 mm, avec des vestiges de circulation d'eau	30-105	7-12	Classe III-IV raisonnable à mauvaise	Catégorie IV-V Roches résistantes à très résistantes

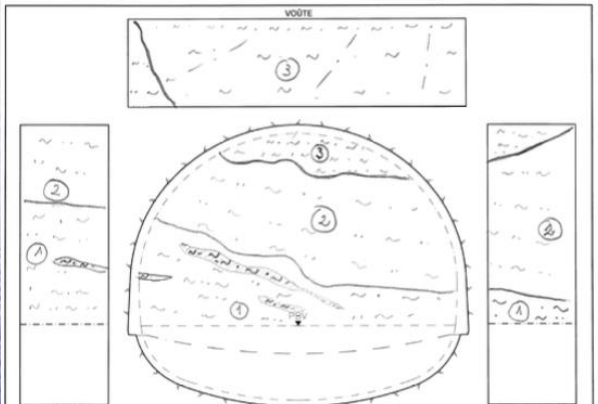
Zonamento do Maciço - Tipos de Sustimento

Classes rocheuses		Soutènements	
Désignation	**RMR**	**Désignation**	**RMR**
CR1	26 – 47	S1	37(±2) – 47
		S2	26 (±2) – 37 (±2)
CR2	12 - 26	S3	< 26 (±2)

Levantamento de Frente de Escavação – Ficha RMR

GMAC
Groupement Metro D'Alger Centre
Andrade Gutierrez - Teixeira Duarte - Gesi-TP - Zagope
CENOR® Consulting Engineers

REGISTRE DU SUIVI GÉOLOGIQUE ET GÉOTECHNIQUE	Date 25/08/2012	Page 1/3
	Référence	
	Localisation TRONÇON 3	
METRO D'ALGER: LIGNE 1 - LOT 1: EXTENSION A PLACE EMIR ABDELKADER - PLACE DES MARTYRS	Pk 0 + 882,50	
RELEVÉ GÉOLOGIQUE DANS LE FRONT D'EXCAVATION	Sens d'excavation	



LÉGENDE

- Schistes
- Calcaires
- Intercallations de schistes et de calcaires
- Argile
- schistes argileux noirs
- Zone de fracture

① Intercalations de schistes argileux gris verdâtres, avec des schistes marrons siliceux
② Schistes marrons siliceux
③ schistes gris blanchâtres, déformés, fracturé

RMR	28	SOUTÈNEMENT	S2

Signature
Par GMAC

GMAC
Groupement Metro D'Alger Centre
Andrade Gutierrez - Teixeira Duarte - Gesi-TP - Zagope
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METRO D'ALGER: LIGNE 1 - LOT 1: EXTENSION A PLACE EMIR ABDELKADER - PLACE DES MARTYRS	Pk 0 + 882,50	

CLASSIFICATION DE BIENIAWSKI (1989) Du Pk ________ au Pk ________

									Poids considéré
Résistance de la roche à la compression uniaxiale	Point Load (MPa)	>10	4-10	2-4	1-2				4
	RCU (MPa)	>250	100-250	50-100	25-50	5-25	1-5	<1	
	Poids défini	15	12	7	4	2	1	0	
Qualité de la roche	RQD (%)	90-100	75-90	50-75	25-50	<25			3
	Poids défini	20	17	13	8	3			
Espacement des fractures	Espacement (m)	>2,00	0,60-2,00	0,20-0,60	0,06-0,20	<0,06			5
	Poids défini	20	15	10	8	5			
Conditions des fractures	Longueur (m)	<1	1-3	3-10	10-20	>20			3
	Poids défini	6	4	2	1	0			
	Ouverture (mm)	fermée	<0,1	0,1-1,0	1-5	>5			5
	Poids défini	6	5	4	1	0			
	Rugosité	très rugueuse	rugueuse	légè. rugueuse	lisse	polie			1
	Poids défini	6	5	3	1	0			
	Remplissage	aucun	<5mm,dur	>5mm,dur	<5mm,mou	>5mm,mou			2
	Poids défini	6	4	2	2	0			
	Altération	pas alterée	légè. Alterée	modérée	très altérée	décomposée			3
	Poids défini	6	5	3	1	0			
Eau souterraine	Flux/10 m tunnel	nul	<10 l/min	10-25 l/min	25-125 l/min	>125 l/min			7
	Conditions générales	sec	humide	saturé	fluent	écoulement			
	Poids défini	15	10	7	4	0			
Orientation des discontinuités	Perpendiculaire à l'axe	Favorable à l'excavation			Défavorable à l'excavation				-5
		45º - 90º		20º - 45º	45º - 90º	20º - 45º			
		Très favorable 0		Favorable -2	Raisonnable -5	Défavorable -10			
	Parallèle à l'axe	45º - 90º		20º - 45º					
		Très défavorable (-12)		Raisonnable (-5)					
	Inclinaison 0º - 20º	Raisonnable (-5)							

Soutènement	S2	Zonage		RMR	28

Description: des schistes gris blanchâtres qui on trouve dans la partie supérieure du front d'excavation et dans la voûte, ont une résistance plus faible, que ceux des schistes siliceux et de intercalations de schistes argileux et de schistes siliceux.

Remarques: Il est necessaire de projeter le front d'excavation.

Signature
Par GMAC

GMAC
Groupement Metro D'Alger Centre
Andrade Gutierrez - Teixeira Duarte - Gesi-TP - Zagope
CENOR® Consulting Engineers

REGISTRE DU SUIVI GÉOLOGIQUE ET GÉOTECHNIQUE	Date 25/08/2012	Page 3/3
	Référence	
	Localisation Tronçon 3	
METRO D'ALGER: LIGNE 1 - LOT 1: EXTENSION A PLACE EMIR ABDELKADER - PLACE DES MARTYRS	Pk 0+882,50	

PHOTOGRAPHIES DU FRONT D'EXCAVATION

Voute

Front d'Excavation

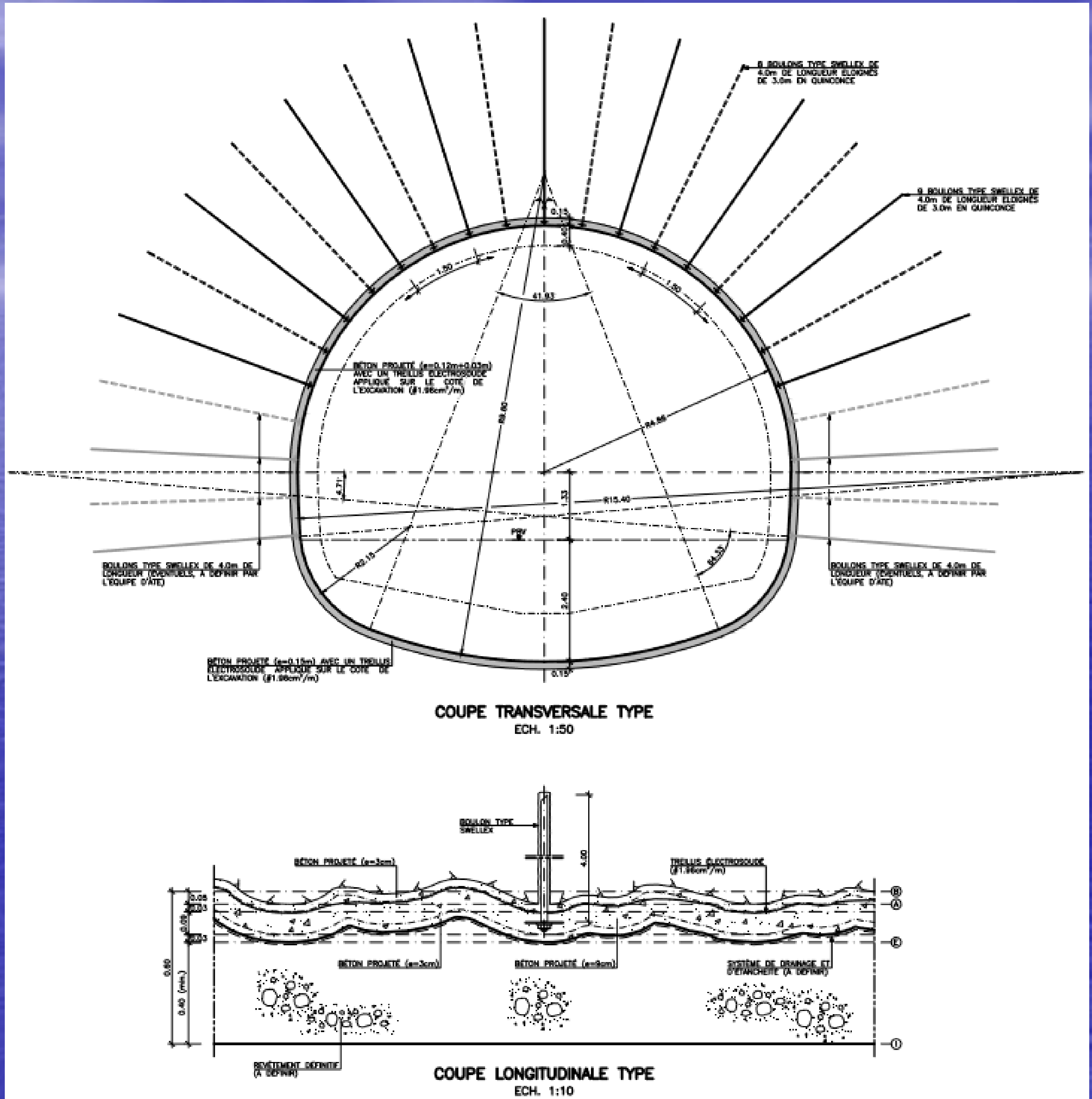
Signature
Par GMAC

Tipos de Sustimento

Soutènement type	Soutènement adopté								Dispositifs auxiliaires	
	Voûte et Piédroits							Radier	Enfilages	Clouages d'acier
	Béton projeté	Boulons			Cintres			Dalle en béton projeté		
	e (cm)	Type	L (m)	Maille	Type	Éloign. (m)				
S1	12 (+ 3 cm d'égalisation) + treillis #1,96 cm²/m	Swellex	4	1,5x1,5	-	-		15 cm + treillis #1,96 cm²/m	-	-
S2	19 (+ 3 cm d'égalisation) + treillis #1,96 cm²/m	-	-	-	HEB120	1,2		15 cm + treillis #1,96 cm²/m	-	✓
S3	25 (+ 3 cm d'égalisation) + treillis #1,96 cm²/m	-	-	-	HEB160	1,0		20 cm + 2 treillis #1,96 cm²/m	✓	-

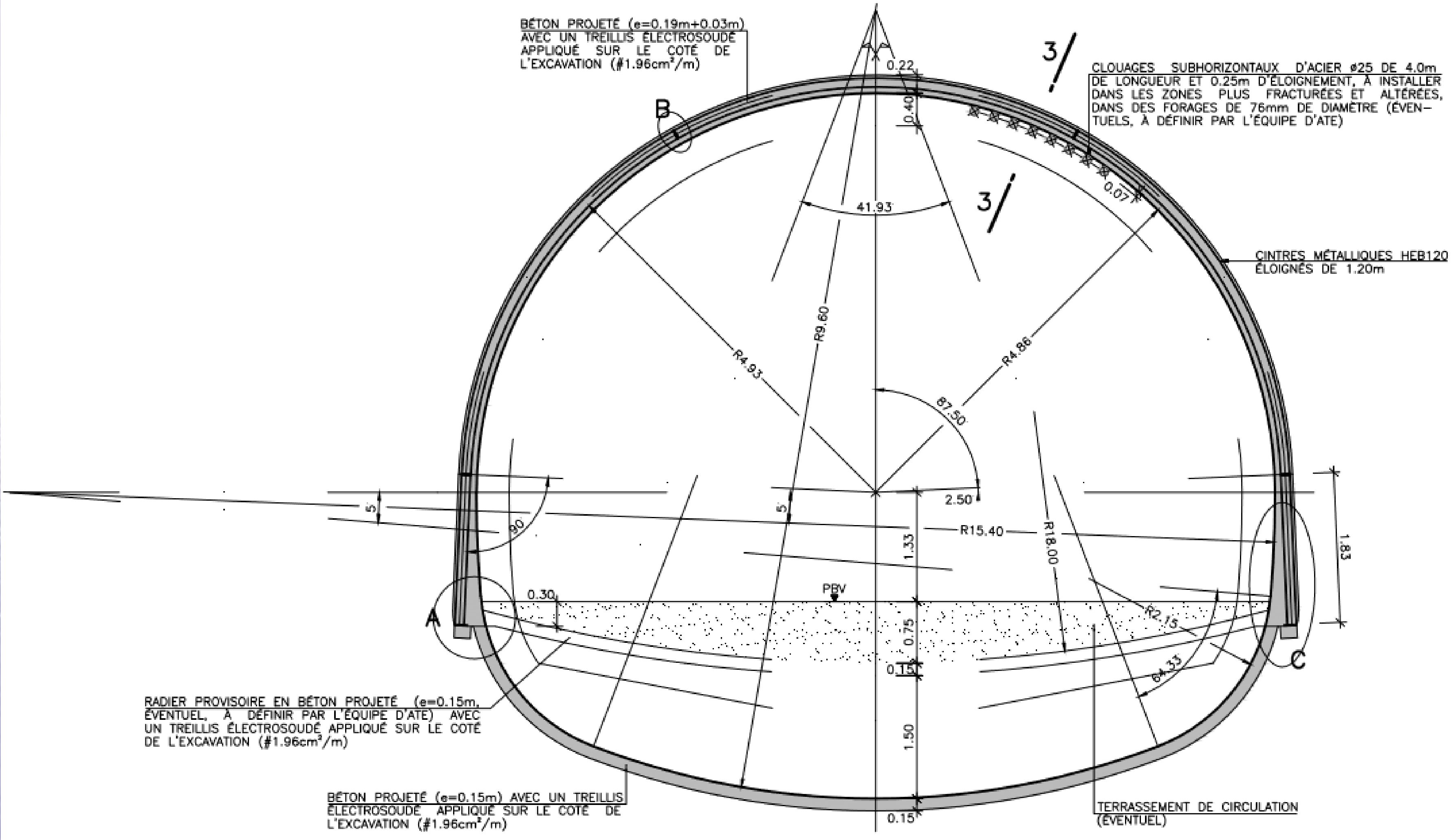
Sustimento S1

37(+/-2) < RMR<47



Sustimento S1 37(+/-2) < RMR<47

Sustimento S2 26 (+/-2) < RMR <37 (+/-2)

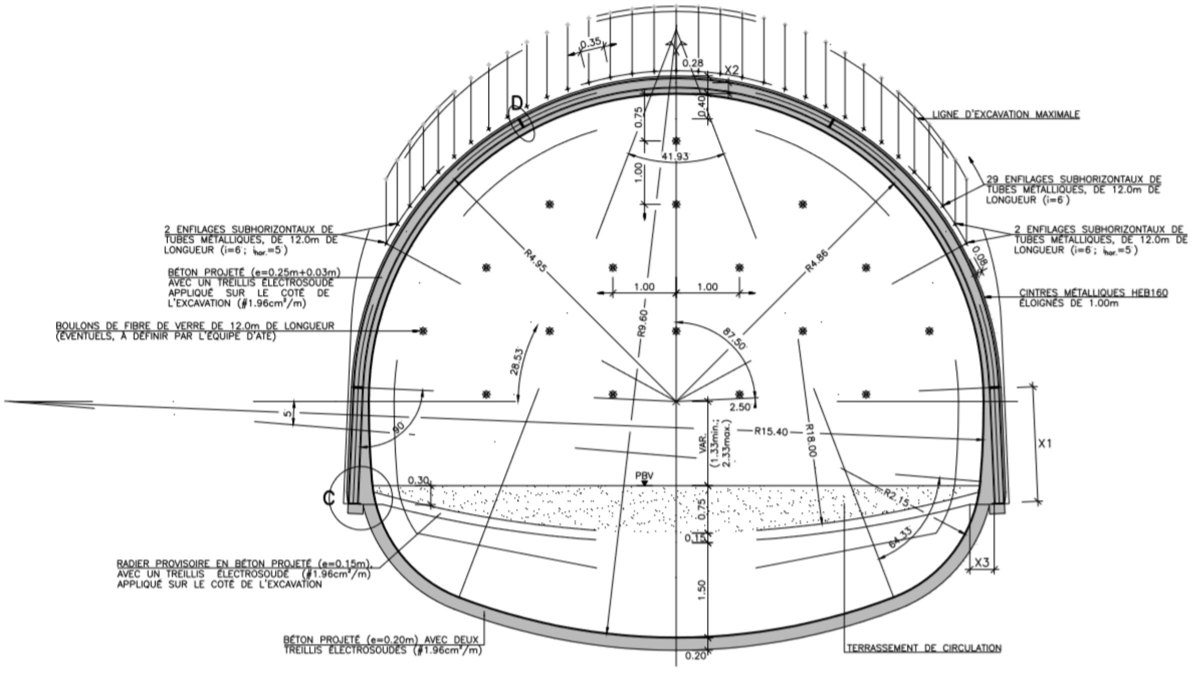


COUPE TRANSVERSALE TYPE

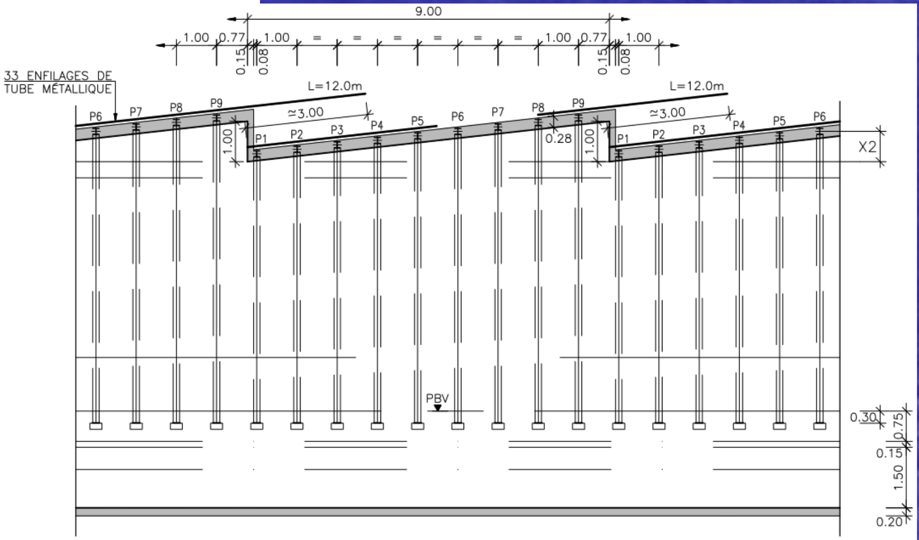
ECH. 1:50

Sustimento S2 **26 (+/-2) < RMR <37 (+/-2)**

Sustimento S3 RMR <26 (+/-2)



COUPE TRANSVERSALE TYPE
ECH. 1:50



COUPE LONGITUDINALE TYPE
SOUTÈNEMENT TYPE S3
ECH. 1:100

Sustimento S3 RMR <26 (+/-2)

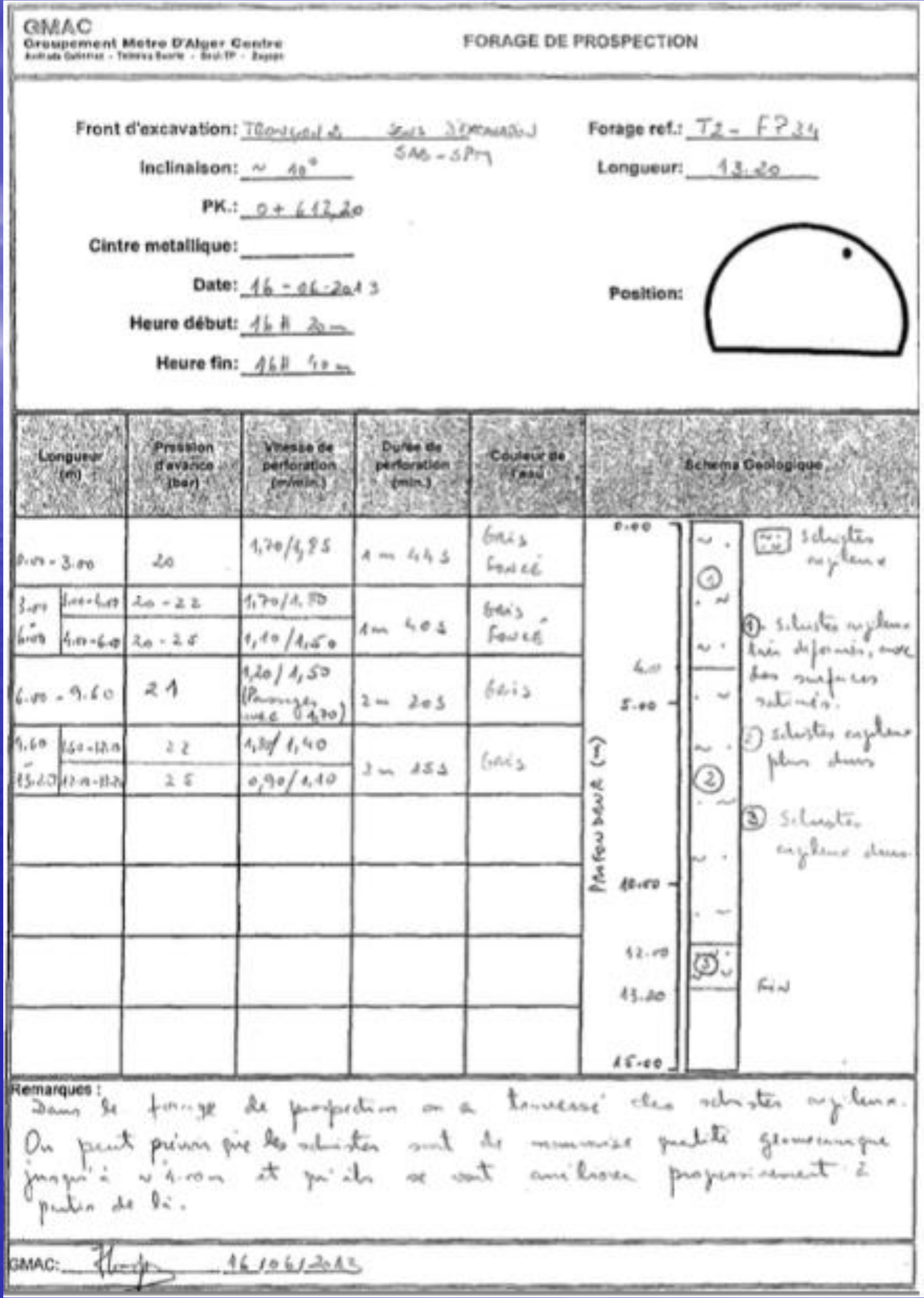
Faseamento Constructivo

Phasage Exécutive type	Phasage Constructif		
	Partialisation	Avancée (m)	Distance minimale entre les fronts (m)
I	Voûte / Stross	1,5 6,8	20,0
II	Voûte + (Radier Provisoire – événtuel) / Stross	1,2 3,4(*) / 4,6(**)	20,0
III	Voûte + (Radier Provisoire) / Stross	1,0 2,4	20,0

(*) Dans les zones avec radier provisoire ; (**) Dans les zones sans radier provisoire

Frente de Escavação – Abóbada e Soleira

Prospecção Frente de Escavação



GMAC
Groupement Metro D'Alger Centre

FORAGE DE PROSPECTION

Front d'excavation: [illegible] SAB - SPm
Forage ref.: T2 - FP34
Inclinaison: ~ 10°
Longueur: 13.20
PK.: 0 + 612,20
Cintre metallique: ______
Date: 16 - 06 - 2013
Position:
Heure début: 16 h 20 m
Heure fin: 16 h 40 m

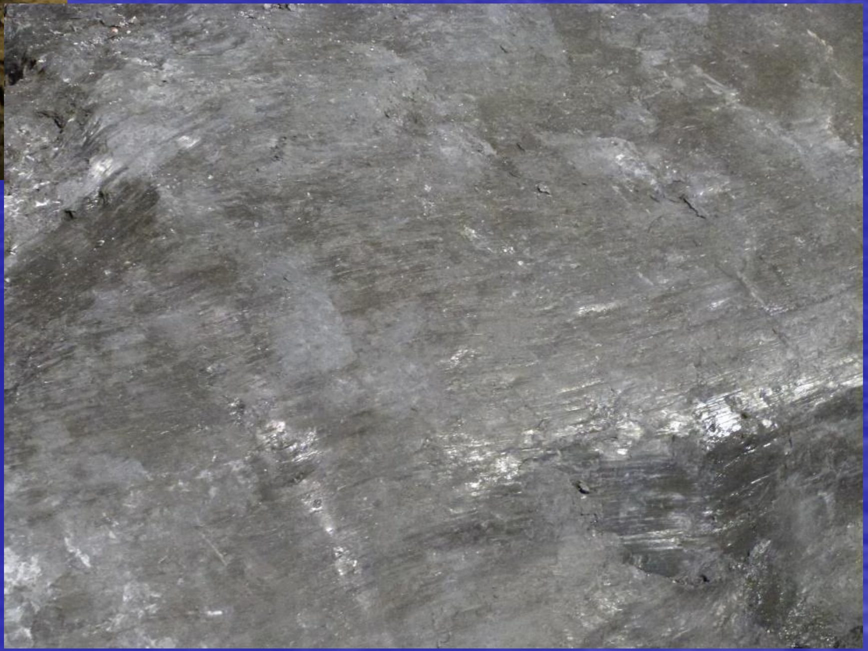
Longueur (m)		Pression d'avance (bar)	Vitesse de perforation (m/min.)	Durée de perforation (min.)	Couleur de l'eau
0.00 - 3.00		20	1,70/1,95	1 m 44 s	Gris foncé
3.00 - 6.00	3.00 - 4.00	20 - 22	1,70/1,80	1 m 40 s	Gris foncé
	4.00 - 6.00	20 - 25	1,10/1,50		
6.00 - 9.60		21	1,20/1,50 (Passages avec 0,70)	2 m 20 s	Gris
9.60 - 13.20	9.60 - 12.00	22	1,30/1,40	3 m 15 s	Gris
	12.00 - 13.20	25	0,90/1,10		

Schema Geologique:
PROFONDEUR (m): 0.00, 4.00, 5.00, 10.00, 12.00, 13.20, 15.00
schistes argileux
① schistes argileux très déformés, avec des surfaces satinées.
② schistes argileux plus durs
③ schistes argileux durs
Fin

Remarques :
Dans le forage de prospection on a traversé des schistes argileux. On peut prévoir que les schistes sont de mauvaise qualité géomécanique jusqu'à ~4.00m et qu'ils se sont améliorés progressivement à partir de là.

GMAC: [signature] 16/06/2013

Instabilização da Frente de Escavação – Zona de Falha



Frente de Escavação – Instabilização da Abóbada do Túnel

Ficha

ATE

METRO D'ALGER : LIGNE 1 – LOT 1 : EXTENSION A PLACE EMIR ABDELKADER – PLACE DES MARTYRS Assistance Technique de l'Exécution	Action No. 36

Localisation : Rameau PV1

Sujet : Suppression des Enfilages

Description :

Le tunnel du rameau du PV1 est excavé jusqu'au au cintre métallique P3.4.
Le front d'excavation est stable et les caractéristiques géomécaniques sont favorables (voir fiche RMR et photo en annexe).
L'instrumentation de l'extensomètre E1 et du nivellement de surface PV1 PS1 et PV1 – PS2 montre que la déformation est négligeable (voir feuille de divulgation de donnés d'instrumentation en annexe).

Solution Proposée :

Face aux caractéristiques géomécaniques du massif, on peut supprimer l'exécution des enfilages.

Lorsqu'il y a un changement de lithologie ou de facteurs qui affectent la stabilité du tunnel, la situation sera réévalué, en prenant en considération l'évolution de l'instrumentation.

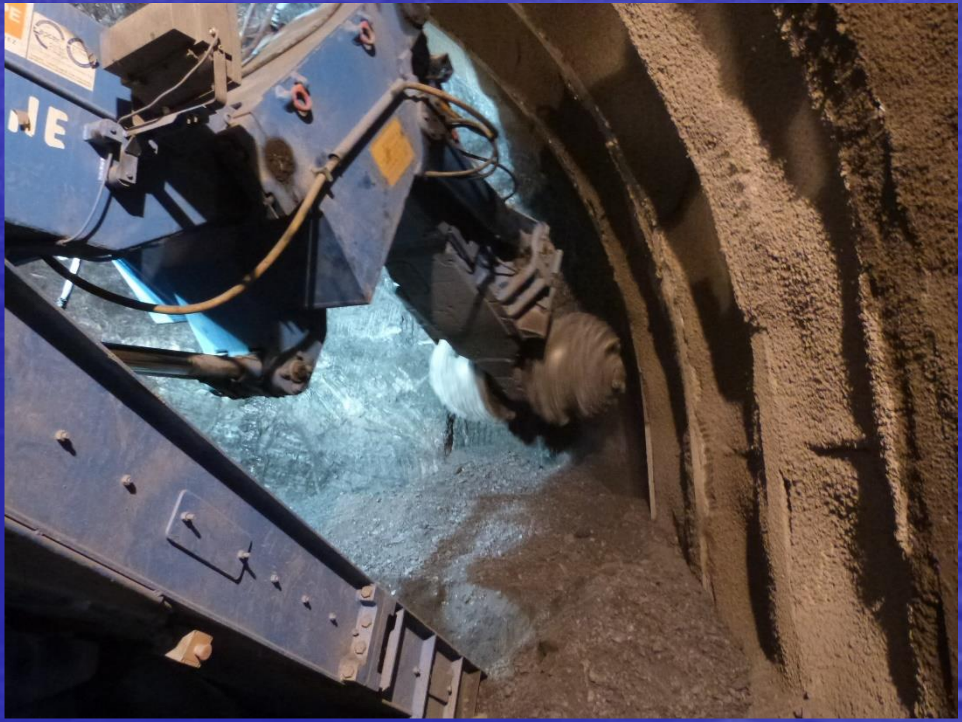
Documents Associés :
L1A GCG GMAC 201 AQ 40 005 A

Documents Annexés :
Fiche RMR du Rameau PV1 cintre métallique P3.4

Photos du front d'excavation
Instrumentation géoméchanique

Escavação de Frente – Martelo Hidráulico

Escavação de Frente – Fresa



Projecção de Betão

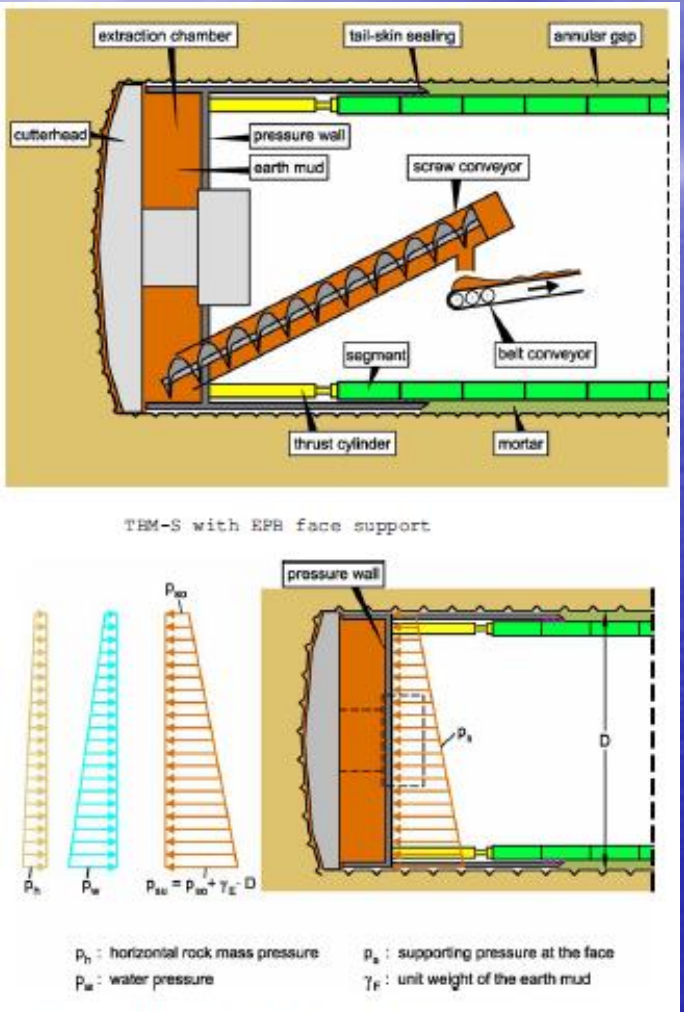
4.7 CONVENTIONAL TUNNELLING - CONCLUSIONS

- Ground is viewed as integrated Element of Support
- Ground reactions are measured to confirm Stability
- Ground should be kept Undisturbed
- Type of Support to allow Most Economical Design
- Tunnelling on Ground Behaviour

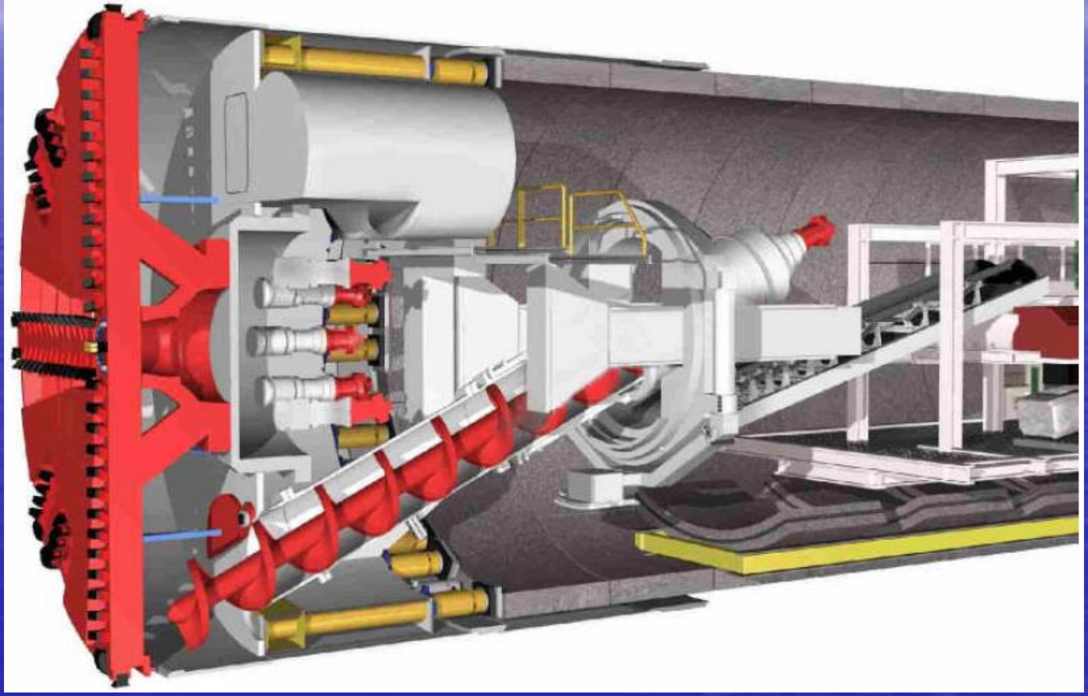
TBM – Doha Green Line

TÚNEIS TBM – Metro do Porto

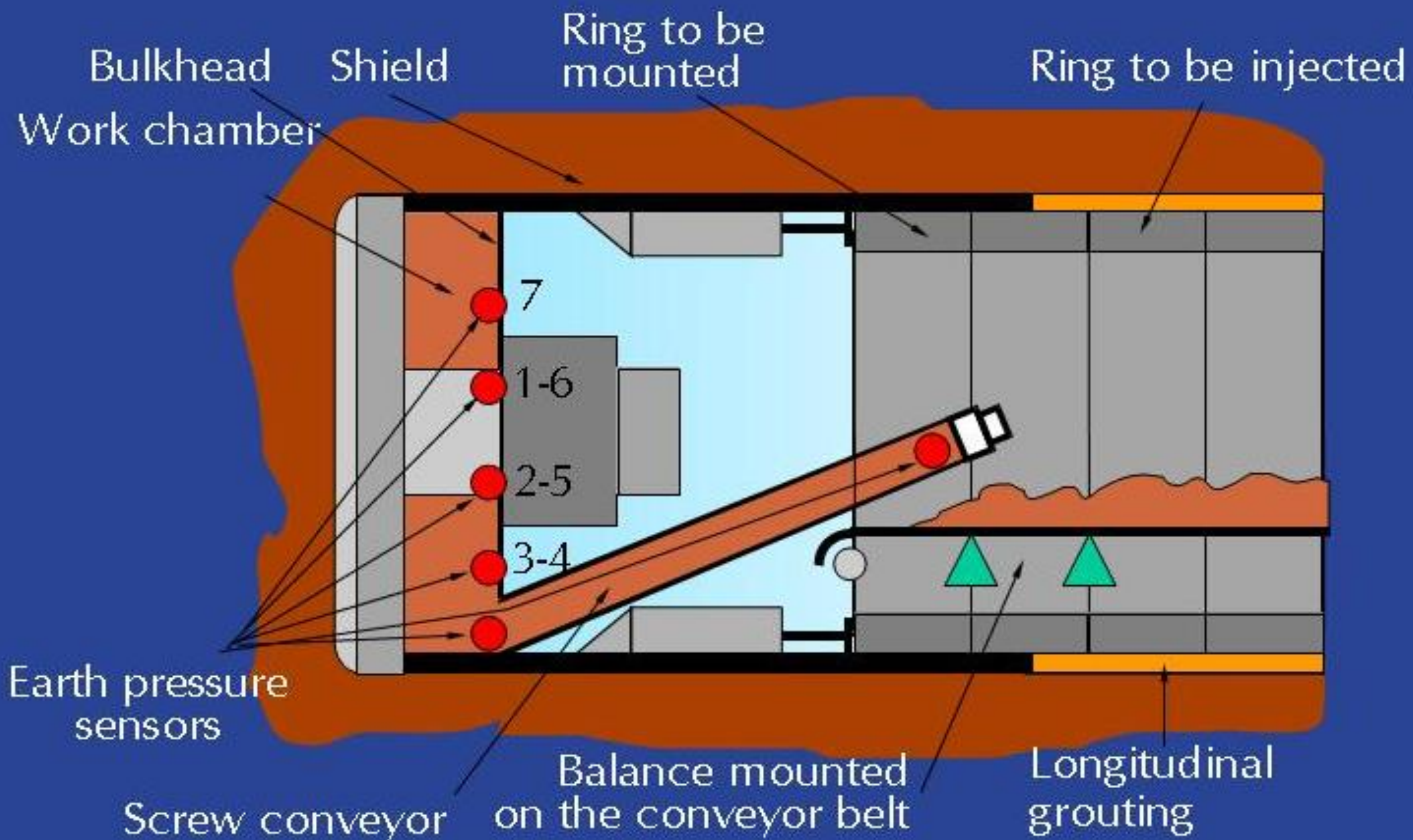
EPB - Escudo



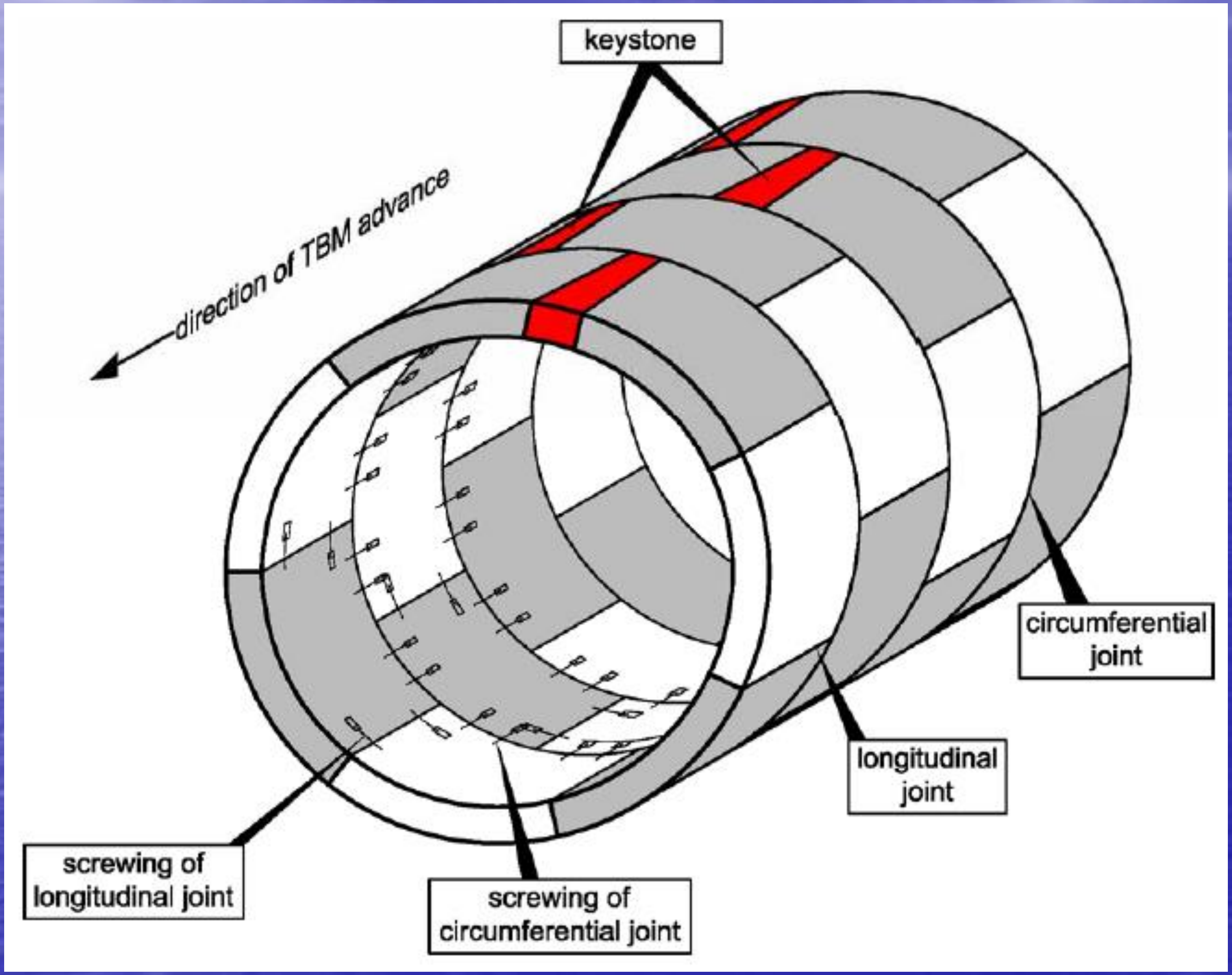
2.19: Principle of earth pressure face support



EPB – Shield Scheme



TBM – Aneis Betão Armado (aduelas)




Esso
Esso

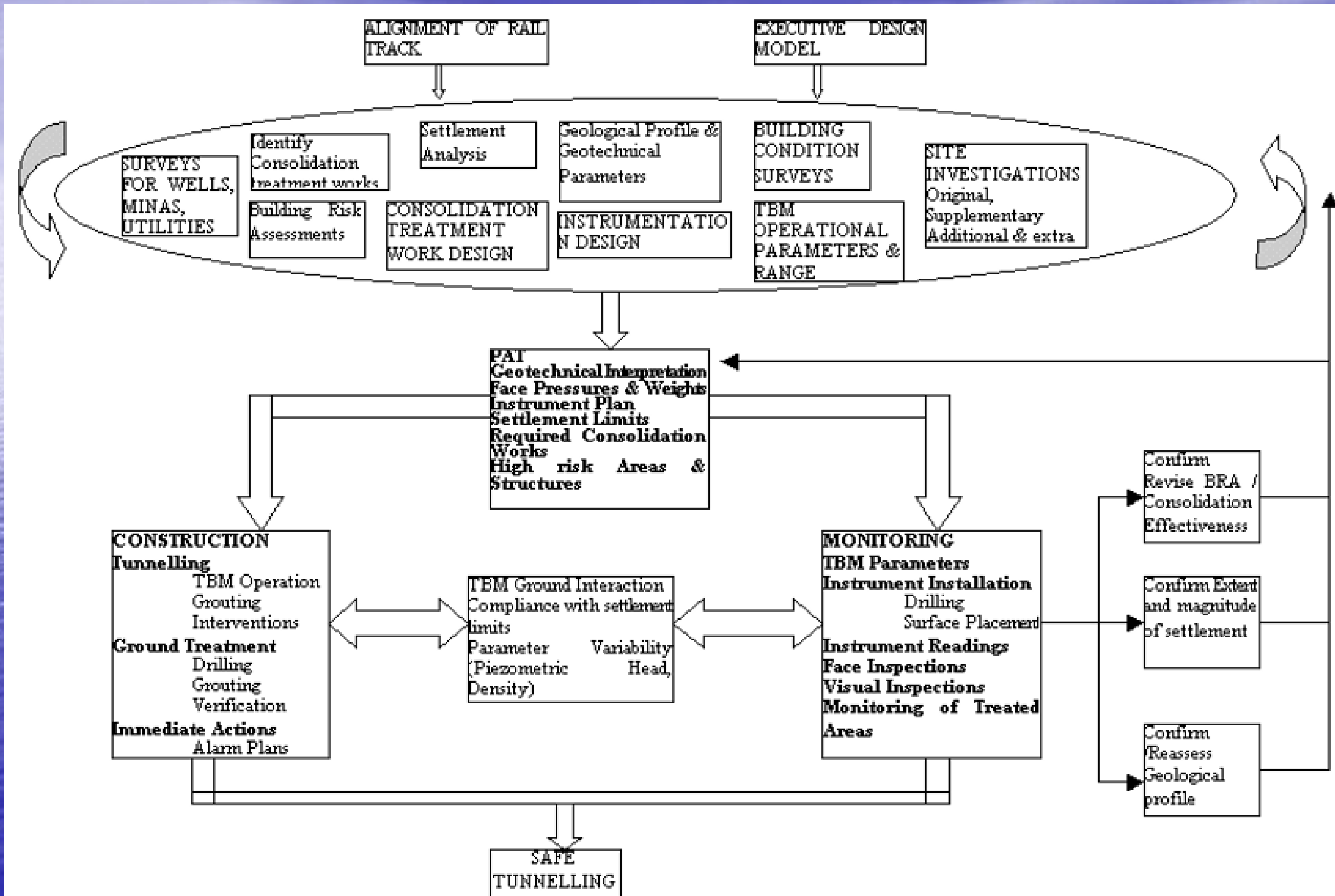
MAIN RISKS AND ADVANTAGES OF MECHANIZED TUNNELLING TECHNIQUES

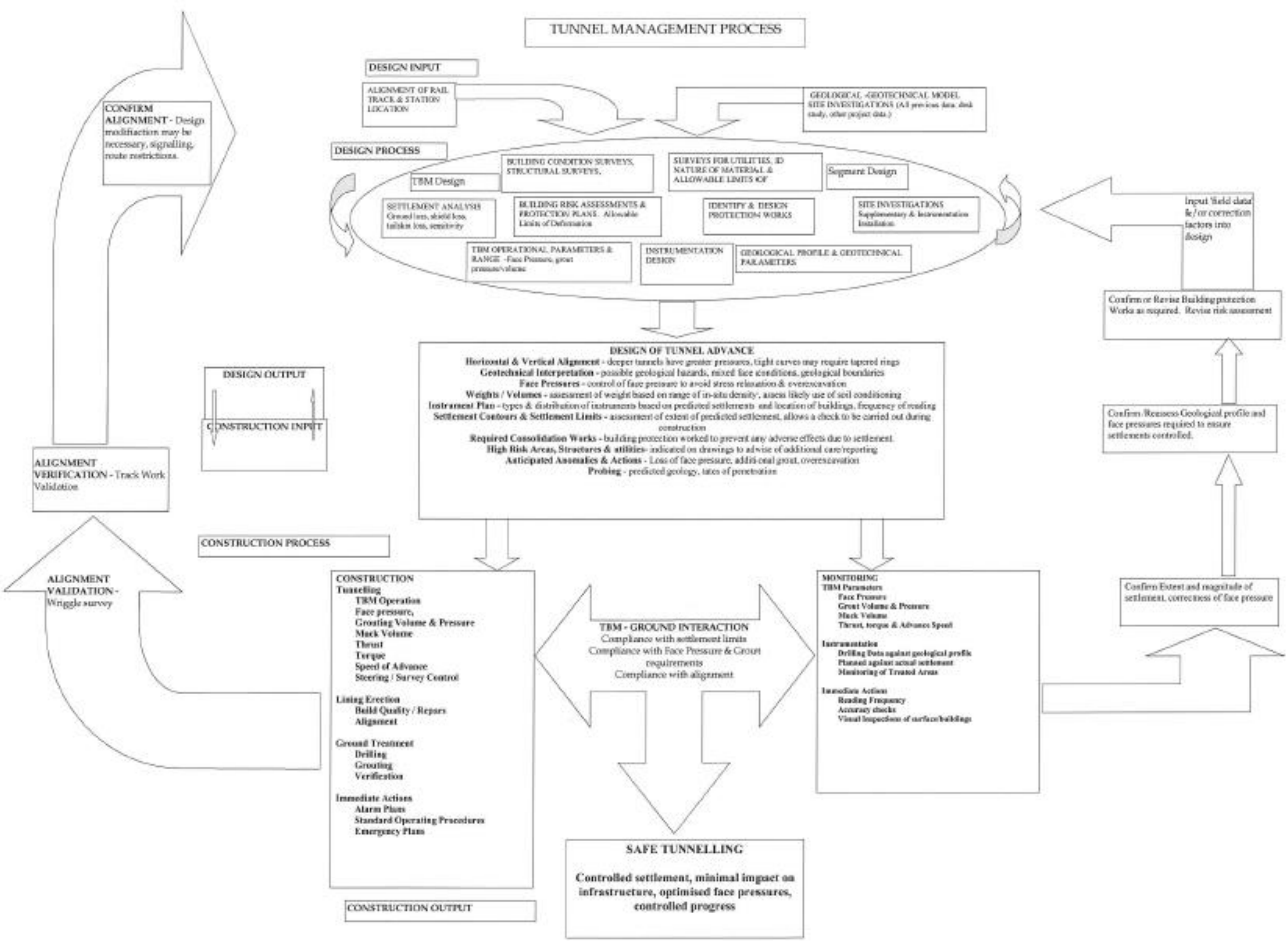
The advantages of mechanized tunnelling are multiple. They are chiefly:

- enhanced health and safety conditions for the workforce,
- industrialization of the tunnelling process, with ensuing reductions in costs and lead-times,
- the possibility some techniques provide of crossing complex geological and hydrogeological conditions safely and economically,
- the good quality of the finished product (surrounding ground less altered, precast concrete lining segments, etc.)

However, there are still risks associated with mechanized tunnelling, for the choice of technique is often irreversible and it is often impossible to change from the technique first applied, or only at the cost of immense upheaval to the design and/or the economics of the project.

Tunel TBM – do Projecto à Construção




TUNNEL MANAGEMENT PROCESS
DESIGN INPUT
ALIGNMENT OF RAIL TRACK & STATION LOCATION
GEOLOGICAL -GEOTECHNICAL MODEL SITE INVESTIGATIONS (All previous data: desk study, other project data.)
DESIGN PROCESS
TBM Design
BUILDING CONDITION SURVEYS, STRUCTURAL SURVEYS.
SURVEYS FOR UTILITIES, ID NATURE OF MATERIAL & ALLOWABLE LIMITS OF
Segment Design
SETTLEMENT ANALYSIS Ground loss, shield loss, tailskin loss, sensitivity
BUILDING RISK ASSESSMENTS & PROTECTION PLANS. Allowable Limits of Deformation
IDENTIFY & DESIGN PROTECTION WORKS
SITE INVESTIGATIONS Supplementary & Instrumentation Installation
TBM OPERATIONAL PARAMETERS & RANGE -Face Pressure, grout pressure/volume
INSTRUMENTATION DESIGN
GEOLOGICAL PROFILE & GEOTECHNICAL PARAMETERS
CONFIRM ALIGNMENT - Design modification may be necessary, signalling, route restrictions.
Input 'field data' &/or correction factors into design
Confirm or Revise Building protection Works as required. Revise risk assessment
DESIGN OF TUNNEL ADVANCE
Horizontal & Vertical Alignment - deeper tunnels have greater pressures, tight curves may require tapered rings
Geotechnical Interpretation - possible geological hazards, mixed face conditions, geological boundaries
Face Pressures - control of face pressure to avoid stress relaxation & overexcavation
Weights / Volumes - assessment of weight based on range of in-situ density', assess likely use of soil conditioning
Instrument Plan - types & distribution of instruments based on predicted settlements and location of buildings, frequency of reading
Settlement Contours & Settlement Limits - assessment of extent of predicted settlement, allows a check to be carried out during construction
Required Consolidation Works - building protection worked to prevent any adverse effects due to settlement.
High Risk Areas, Structures & utilities- indicated on drawings to advise of additional care/reporting
Anticipated Anomalies & Actions - Loss of face pressure, additional grout, overexcavation
Probing - predicted geology, rates of penetration
DESIGN OUTPUT
CONSTRUCTION INPUT
Confirm /Reassess Geological profile and face pressures required to ensure settlements controlled.
ALIGNMENT VERIFICATION - Track Work Validation
CONSTRUCTION PROCESS
ALIGNMENT VALIDATION - Wriggle survey
CONSTRUCTION
Tunnelling
TBM Operation
Face pressure,
Grouting Volume & Pressure
Muck Volume
Thrust
Torque
Speed of Advance
Steering / Survey Control
Lining Erection
Build Quality / Repairs
Alignment
Ground Treatment
Drilling
Grouting
Verification
Immediate Actions
Alarm Plans
Standard Operating Procedures
Emergency Plans
TBM - GROUND INTERACTION
Compliance with settlement limits
Compliance with Face Pressure & Grout requirements
Compliance with alignment
MONITORING
TBM Parameters
Face Pressure
Grout Volume & Pressure
Muck Volume
Thrust, torque & Advance Speed
Instrumentation
Drilling Data against geological profile
Planned against actual settlement
Monitoring of Treated Areas
Immediate Actions
Reading Frequency
Accuracy checks
Visual Inspections of surface/buildings
Confirm Extent and magnitude of settlement, correctness of face pressure
SAFE TUNNELLING
Controlled settlement, minimal impact on infrastructure, optimised face pressures, controlled progress
CONSTRUCTION OUTPUT

TBM: Metro do Porto

ENQUADRAMENTO GEOLÓGICO

- Formação geológica predominante: “Granito do Porto” (rochas ígneas da idade Hercínica)
  - intensamente fracturado
  - perfis de alteração muito irregulares

⇨ Variação acentuada e brusca das características físicas e mecânicas

HIDROGEOLOGIA

- diferenças de permeabilidade a pequena escala
- circulação de água subterrânea influenciada pela existência de poços e galerias de água

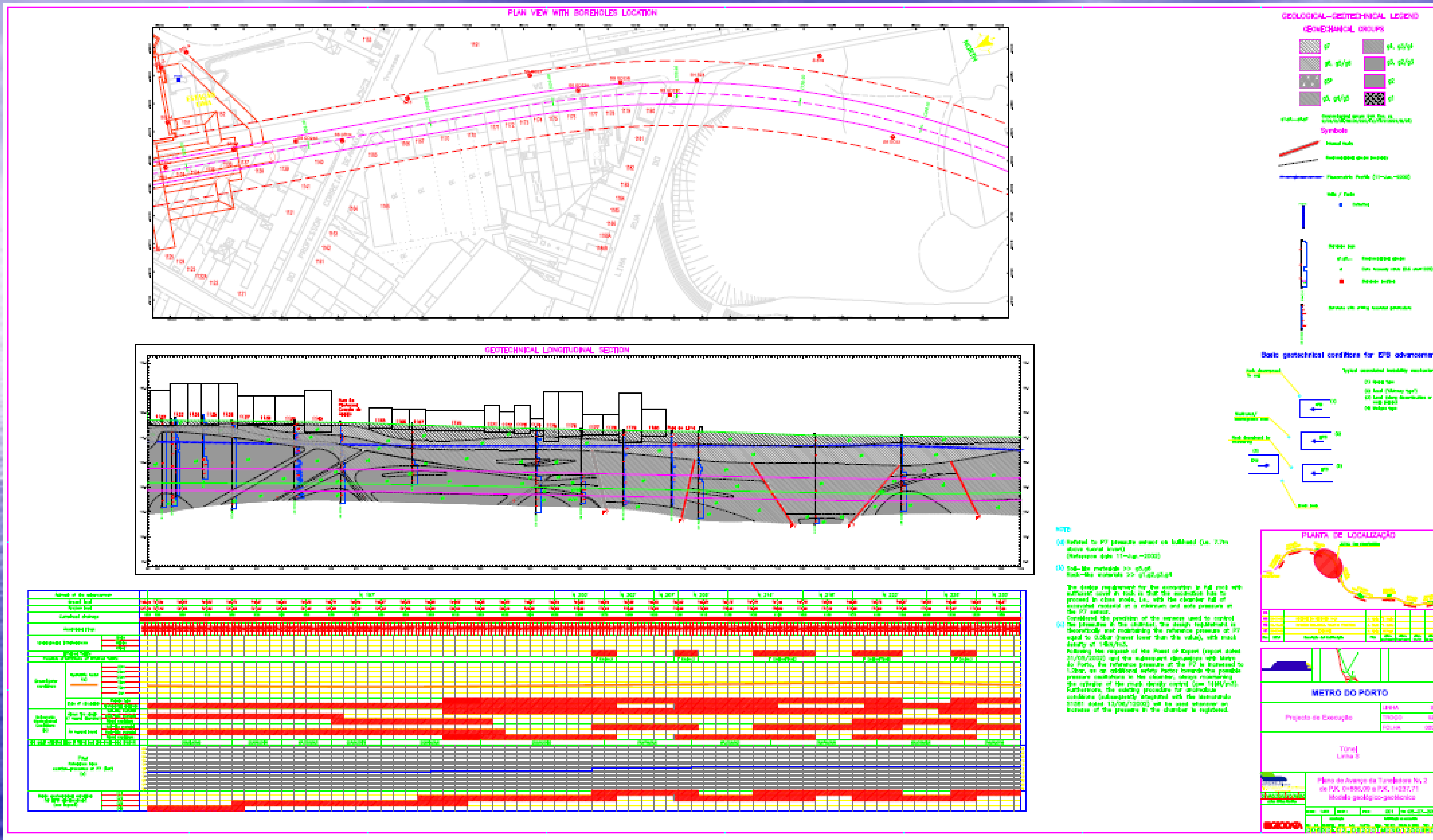
CARACTERIZAÇÃO GEOMECÂNICA

Grupo Geomecânico	Alteração (W)	Fracturação (F)	GSI	NSPT
G1	W1	F1-F2	65-85	-
G2	W2	F2-F3	45-65	-
G3	W3	F3-F4	30-45	-
G4	W4	F4-F5	15-30	-
G5	W5	n.a.	-	> 50
G6	W5/W6	n.a.	n.a.	< 50
G7	n.a.	n.a.	n.a.	var.

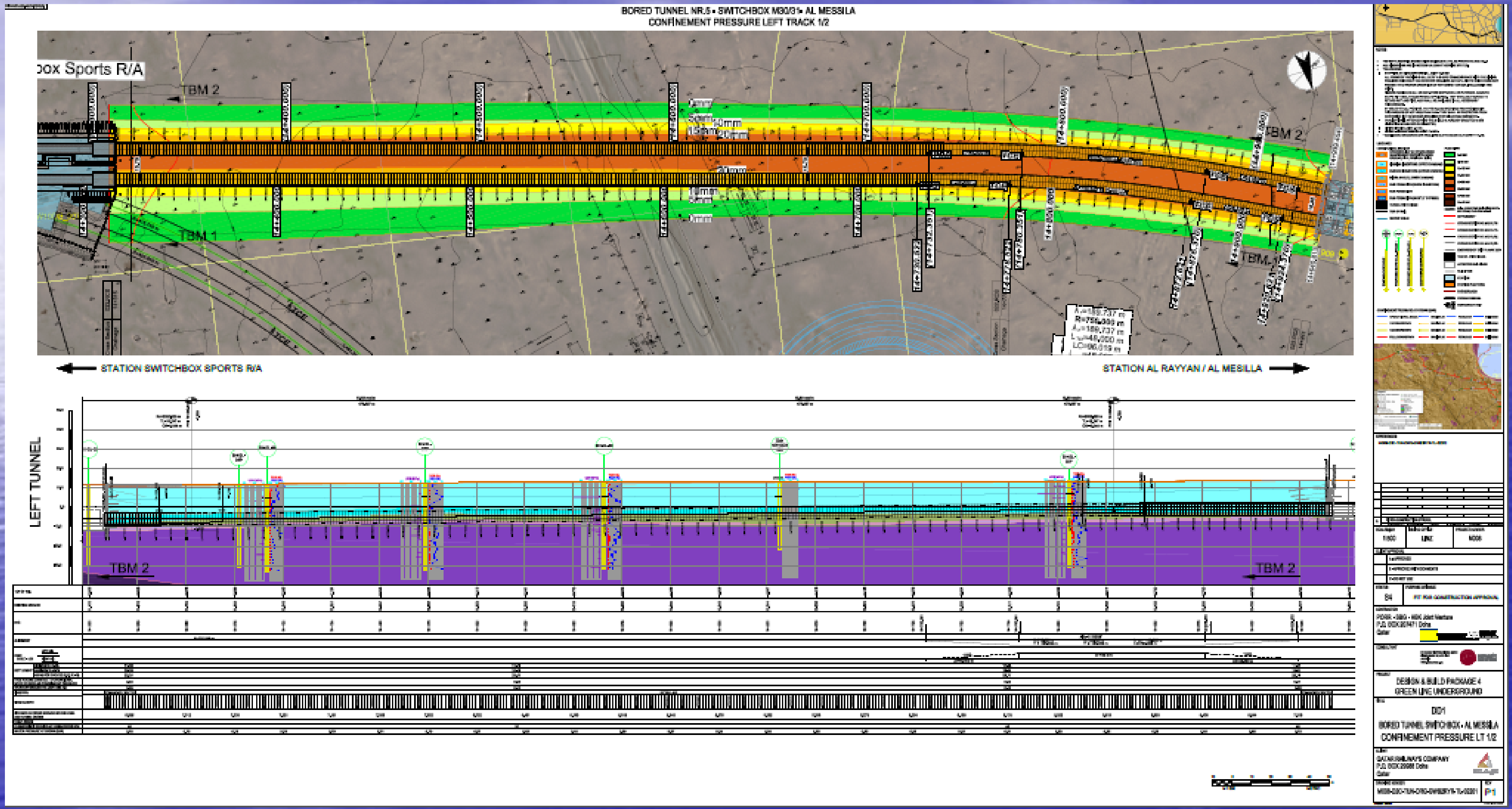
		C_0 (MPa)	γ (kN/m3)	mb	S	Ed (GPa)
ROCHA	G1	90-150	25-27	7.45	6.9E-2	35
	G2	30-90	25-27	3.2	7.5E-3	10.7
	G3	10-35	23-25	0.98	7.5E-4	1.0
	G4	1-15	22-24	0.67	0	0.4

		N_{SPT}	γ (kN/m3)	c' (Mpa)	ϕ' (°)	Ed (GPa)
SOLO	G5	> 50	19-21	0.01-0.05	32-36	0.05-0.20
	G6	< 50	18-20	0-0.02	30-34	0.02-0.07
	G7	variável	18-20	0	27-29	<0.05

TBM: Metro do Porto

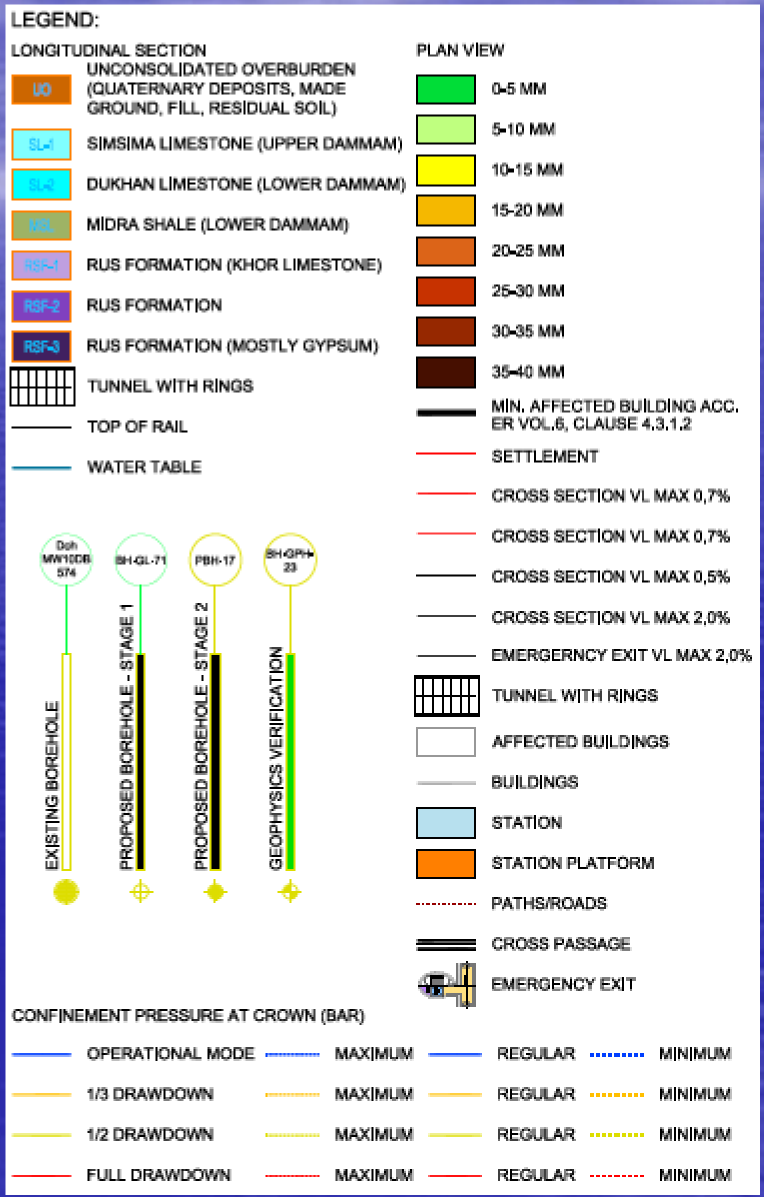


TBM: Doha Green Line Underground



TBM: Doha Green Line Underground

TOP OF RAIL		
EXISTING GROUND		
RTC		
ALIGNMENT		
CANT SCALE = 1:20	LEFT RAIL	
	RIGHT RAIL	
SETTLEMENT	MINIMUM VL=0.5%	
	MAXIMUM VL=0,7%	
	MAX AS PER ER VOL7/CL13.1.2; VL=1%	
FACE VOLUME LOSS DUE TO OPERATIONAL MODE OF REGULAR CONFEINMENT PRESSURE		
RELEVANT GROUND VOLUME LOSS (%)		
RINGTYPE		
RING NUMBER		
DISTANCE BETWEEN GROUND WATER LEVEL AND TUNNEL CROWN		
FAULT ZONES		
CHARACTERISTIC COHESION AT TUNNEL CENTER (kPa)		
WATER PRESSURE AT CROWN (BAR)		



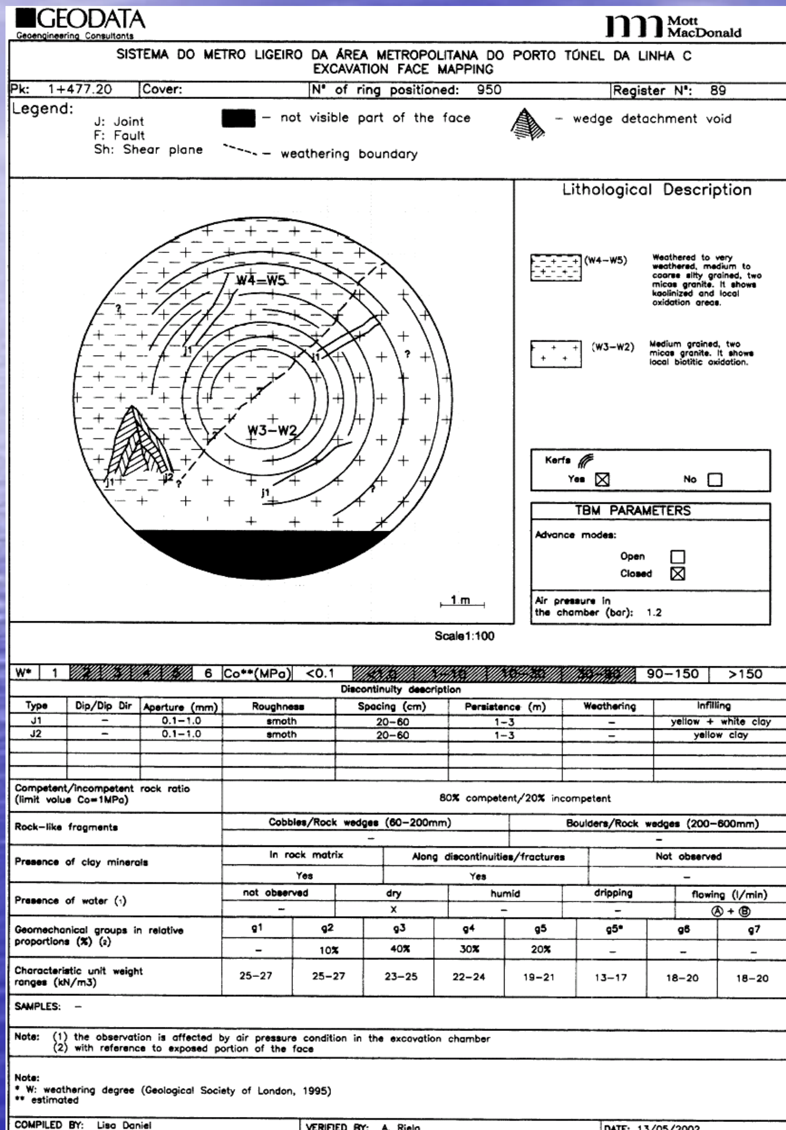
TBM – Prospeccção

Frente de Escavação

Types of soil/rock mass investigations used ahead TBM face

INVESTIGATION TYPE	NOTE
Direct investigation	
Boreholes with core recovery	Horizontal boreholes are normally performed through the TBM cutting head; inclined boreholes are normally possible immediately behind the cutting head in open TBM, through the shield in shielded TBM. Radial boreholes are possible in all TBM types through the lining. The objective of boreholes is to: _ determine the lithological nature of the ground to be excavated through by the TBM _ determine the presence of water _ determine thepresence of voids (karst) and/or decompressed zones; The drilling is realized with a rig positioned behind the TBM cutting head. In the case of shielded TBMs, it is also possible to utilize a "preventer" system to avoid the ingress of groundwater to the tunnel during execution of the drilling. Horizontal and/or inclined boreholes with core-recovery is not commonly used because the time and drilling diameter required.
Boreholes without core recovery	The method of no-core-recovery with registration of the following drilling parameters using a data-logger. _ drilling rate (VA, m/h) ; _ pressure on drill bit (PO,bar) ; _ pressure of the drilling fluid (PI, bar) ; _ torque (CR, bar) ; It is possible to use either a drilling hammer or a tricone bit. The diameter of the drill hole may be limited to 75mm, whereas the drilling rods may be of the aluminum type in order to reduce potential problems associated with the advance of the TBM later in the case that the drilling rods might be completely lost in the drill hole.
Geostructural mapping of the face and/or of the sidewalls	The mapping must be performed using the same methodologies adopted for the face mapping in tunnels excavated by conventional methods. This type of investigation can be performed only when the TBM stops excavation and thus it can be executed at more or less regular intervals in function of the various construction needs. The mapping involves the collection of all geological, structural and geomechanical data of the soil/rock mass. The purpose of this kind of investigation is: _direct characterization and classification of the soil/rock mass; _calibration of all construction parameters which may permit indirect characterization of the rock mass.
Indirect investigation	
Georadar (in borehole)	
Other borehole logs	Gamma ray log Neutron logs Geoelectric logs
Seismic methods	Tunnel Seismic Prediction method (TSP) Soft Ground Sonic Probing System (SSP)

TBM - Cartografia da Frente do Túnel



GEODATA
Geoengineering Consultants

Mott MacDonald

SISTEMA DO METRO LIGEIRO DA ÁREA METROPOLITANA DO PORTO TÚNEL DA LINHA C
EXCAVATION FACE MAPPING

Pk: 1+477.20	Cover:	N° of ring positioned: 950	Register N°: 89

Legend:
J: Joint
F: Fault
Sh: Shear plane
– not visible part of the face
– weathering boundary
– wedge detachment void

Lithological Description

(W4–W5) Weathered to very weathered, medium to coarse silty grained, two micas granite. It shows kaolinized and local oxidation areas.

(W3–W2) Medium grained, two micas granite. It shows local biotitic oxidation.

Kerfs: Yes ☒ No ☐

TBM PARAMETERS

Advance modes:
Open ☐
Closed ☒

Air pressure in the chamber (bar): 1.2

Scale1:100

W*	1	2	3	4	5	6	Co**(MPa)	<0.1	<1.0	1–10	10–50	50–90	90–150	>150

Discontinuity description

Type	Dip/Dip Dir	Aperture (mm)	Roughness	Spacing (cm)	Persistence (m)	Weathering	Infilling
J1	–	0.1–1.0	smoth	20–60	1–3	–	yellow + white clay
J2	–	0.1–1.0	smoth	20–60	1–3	–	yellow clay

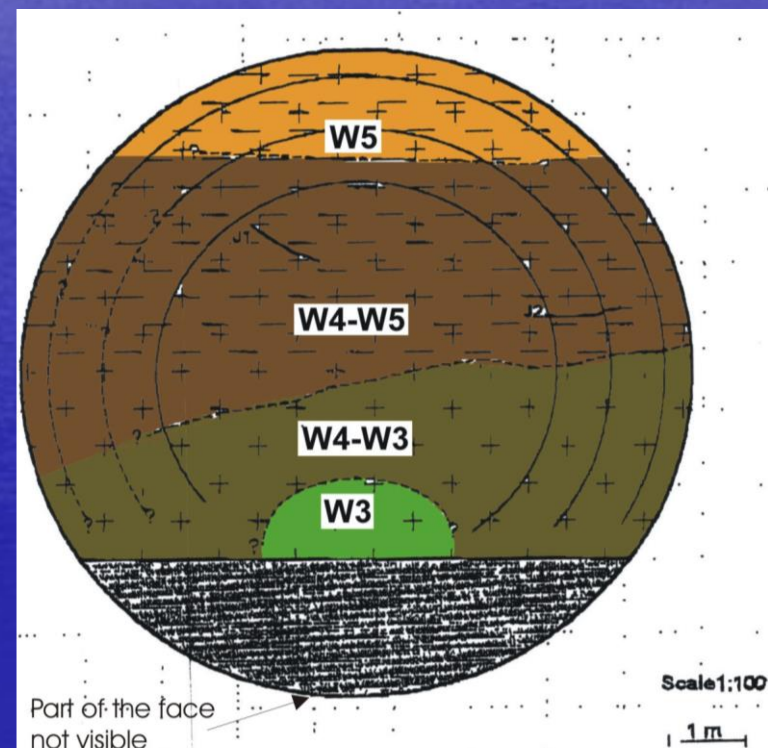
Competent/incompetent rock ratio (limit value Co=1MPa)	80% competent/20% incompetent							
Rock-like fragments	Cobbles/Rock wedges (60–200mm)				Boulders/Rock wedges (200–600mm)			
	–				–			
Presence of clay minerals	In rock matrix		Along discontinuities/fractures			Not observed		
	Yes		Yes			–		
Presence of water (1)	not observed	dry		humid		dripping	flowing (l/min)	
	–	x		–		–	Ⓐ + Ⓑ	
Geomechanical groups in relative proportions (%) (2)	g1	g2	g3	g4	g5	g5*	g6	g7
	–	10%	40%	30%	20%	–	–	–
Characteristic unit weight ranges (kN/m3)	25–27	25–27	23–25	22–24	19–21	13–17	18–20	18–20

SAMPLES: –

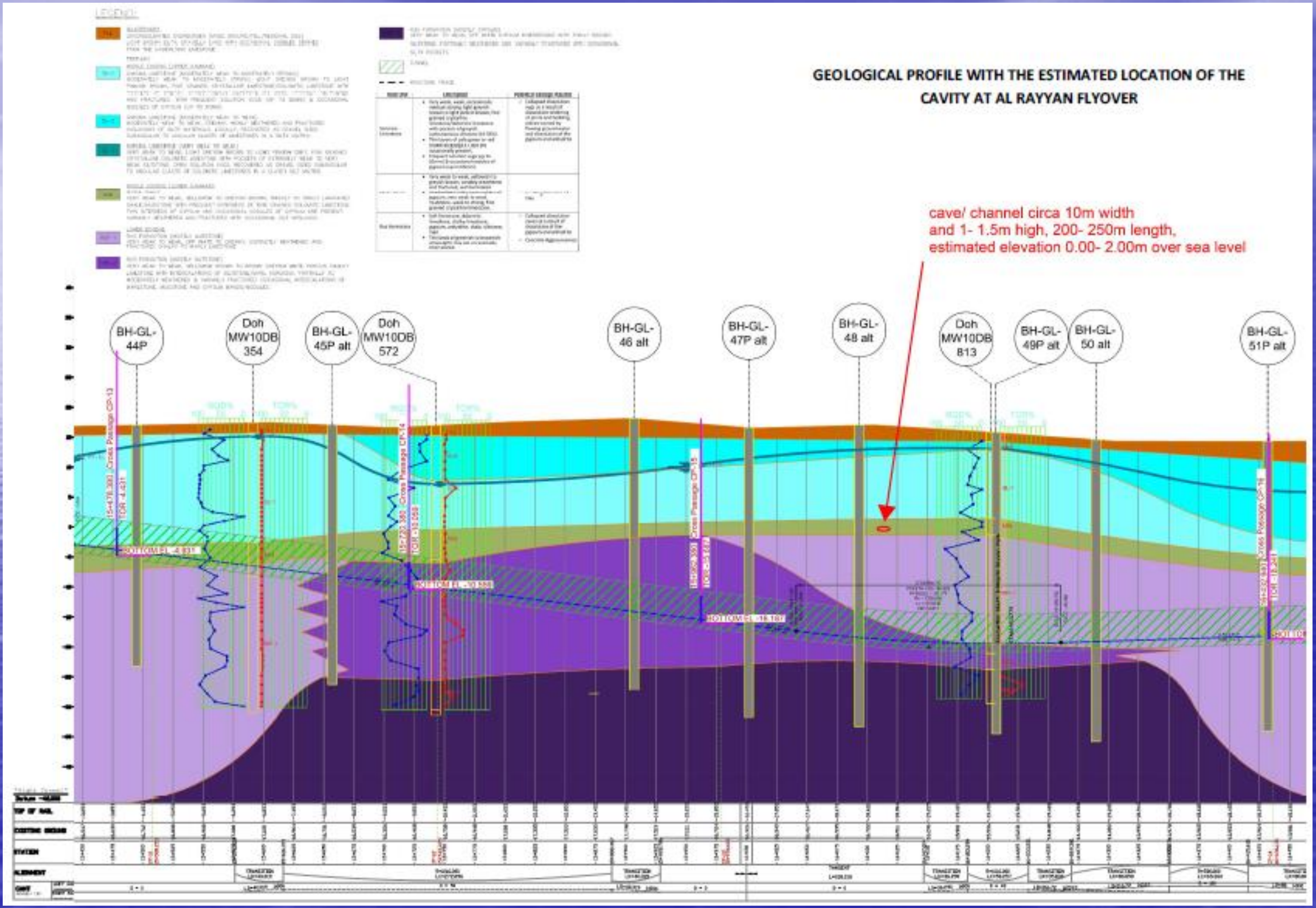
Note: (1) the observation is affected by air pressure condition in the excavation chamber
(2) with reference to exposed portion of the face

Note:
* W: weathering degree (Geological Society of London, 1995)
** estimated

COMPILED BY: Lisa Daniel	VERIFIED BY: A. Riela	DATE: 13/05/2002



Perfil Geológico

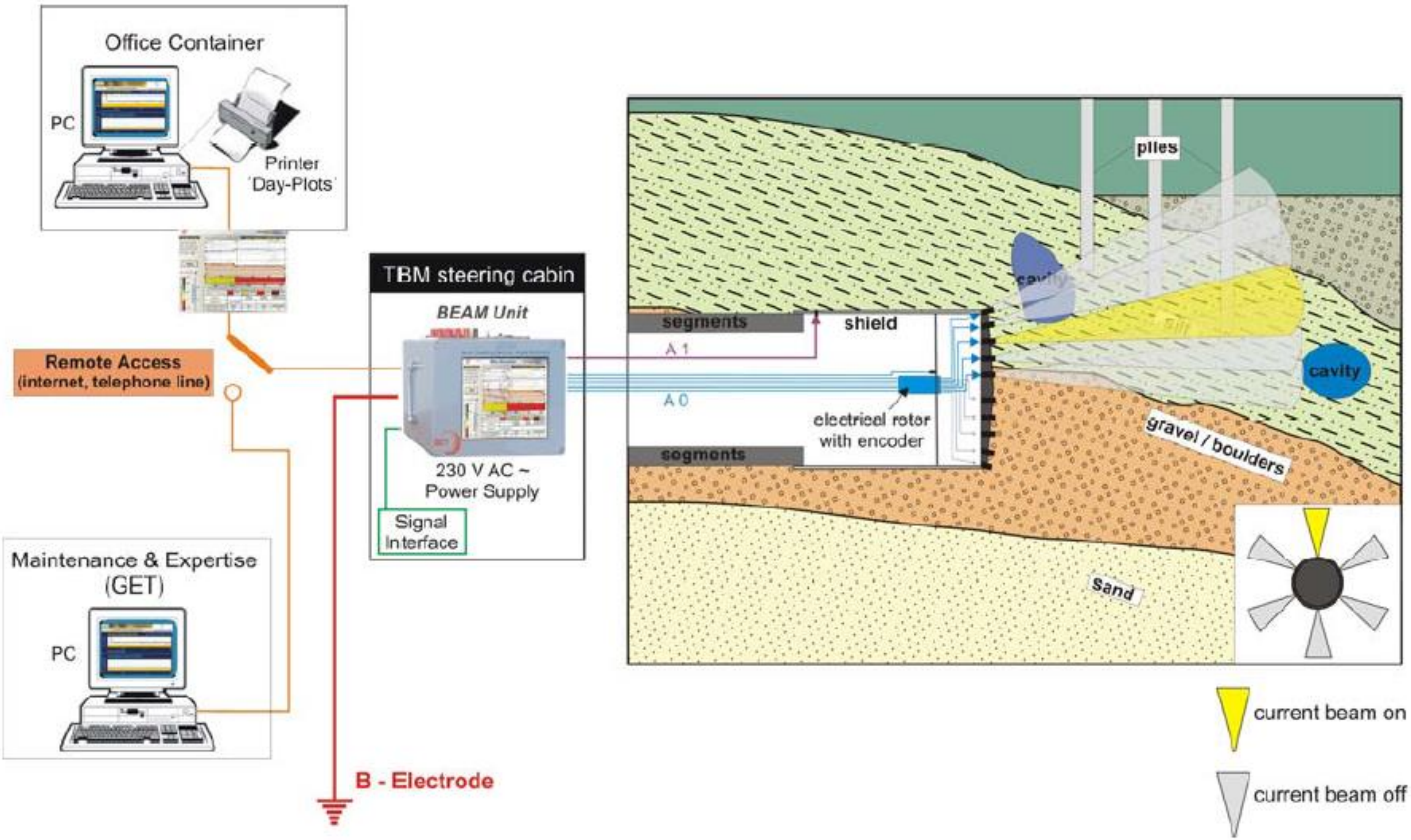


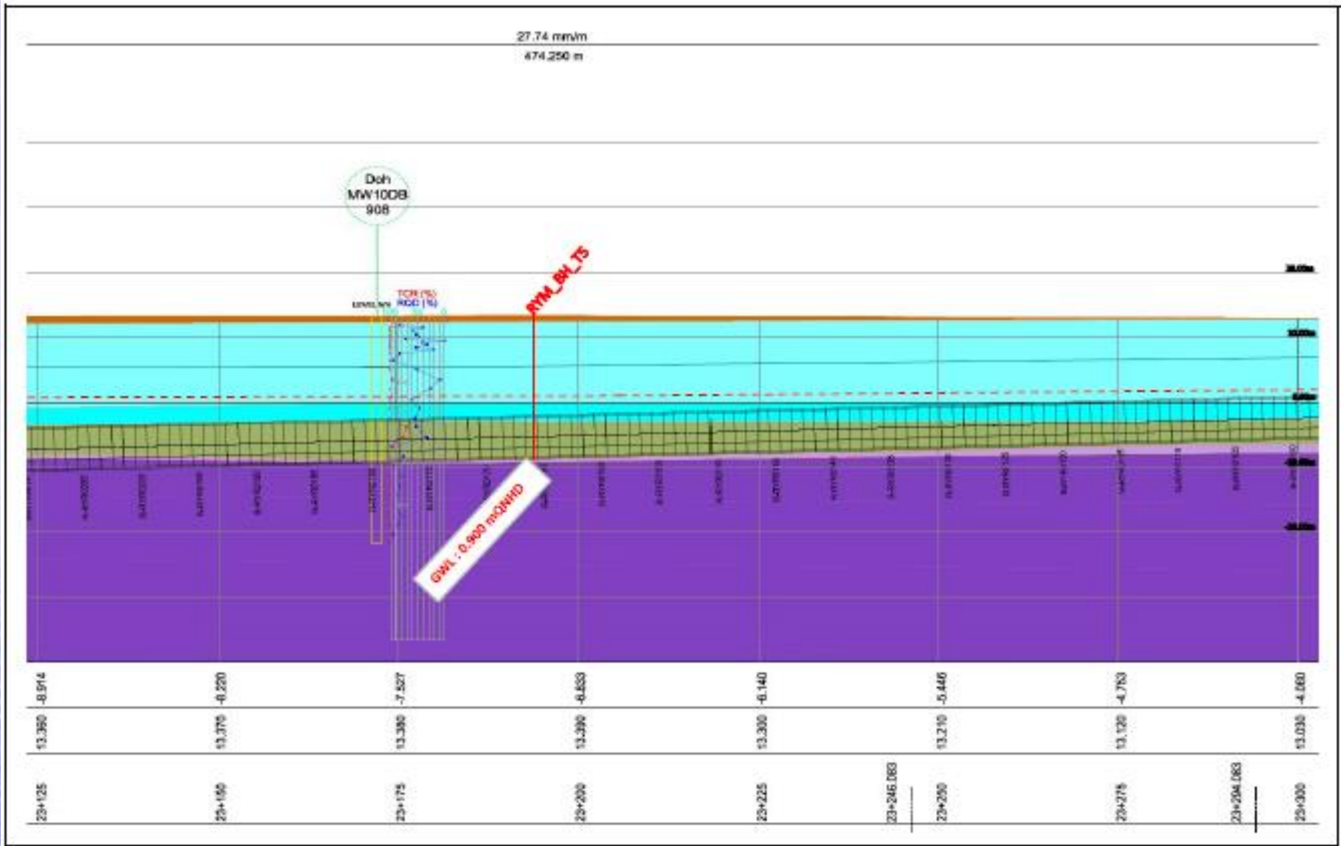
Riscos Associados a Maciços Cársicos

Risks associated with Karstic Terrain

RISK	CAUSE	CONSEQUENCE	MITIGATION
Collapse of TBM into void	Void in invert of sufficient size/bridging to allow TBM to 'drop'.	TBM offline, TBM recovery	
Tunnel offline, steering not possible	Inadequate purchase to face, voids to left/right/crown/invert.	TBM steers (veers) L/R or down/up. Tunnel alignment affected. TBM positioning affected.	
Lining moves after TBM advances	Voids peripheral to tunnel are in close enough proximity and size to allow differential loading.	Damage to ring, bolts shear, gaskets damaged	
Collapse of ground while tunnelling	Voids propagate to surface	Differential settlement, potholes, building / utility / road damage.	
	Uncontrolled water flow causing erosion / sinkhole development		
	Overexcavation as voids above tunnel 'collapse' during TBM advance.	Flooding of Tunnel	
Collapse of ground due to excavation	Anchors/piles affecting pre-existing voids	Differential settlement, potholes, building / utility / road damage. Station Collapse	
	Uncontrolled water inflow and erosion		
	Dewatering and changes to hydrological regime and sinkhole growth.		No open excavations / recharge wells. EVIDENCE OF LOW RISK
Collapse of station	Major cavities below station and sinkhole development	Station integrity compromised / collapse / differential movement with Tunnel	Water table and effect on sinkholes

1. General system layout of BEAM-SCAN:





TBM Drive 1: TM156 – TM180 (CH23+250 - CH23+175)
Geology: (Overburden: 13.7m)

Overburden: Simsima Limestone

Crown to Tunnel Axis (3.6m): Dukham Limestone. Dukham Limestone (Weak to Medium Strong 5-15MPa) described as a "Marly Limestone" i.e. calcite rich limestone which may be harder ground, over Midra Shale. Shale rising in face due to inclination of the tunnel drive.

Tunnel Axis to Invert (3.6m): Midra shale

Below Invert: 1m Khor Limestone over Rus Formation

GW: Groundwater above tunnel crown from approx CH23+320.

TBM Drive 1: TM156 – TM280 (CH23+175 - CH23+125)
Geology: (Overburden: 14.1m)

Overburden: Simsima Limestone and Dukham Limestone

Crown to Tunnel Axis (3.6m): Midra Shale

Tunnel Axis to Invert (3.6m): Midra shale over 1m Khor Limestone over Rus Formation. Kohor and Rus rising in the invert from 0.5m to 2.0m due to inclination of the tunnel drive.

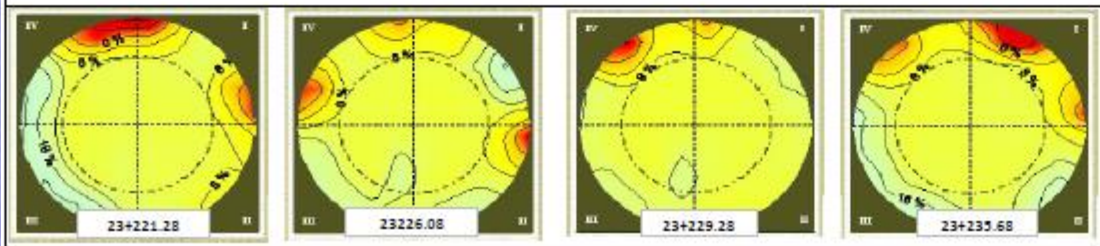
Below Invert: Rus Formation

BEAM: No voids shown to CH23+219.68. Several areas of less dense/ fractured rock containing water are shown, meaning the ground is more permeable, whicg may lead to increased grout uptakes and small loss of pressure.

VOIDS: No voids have been found in either the boreholes or the geophysical surveys.

MONITORING ARRAYS: The next monitoring array's are at and CH+23,215.

STRUCTURES: There are no above ground structures of any significance covered by the this look ahead.



Drive Messila Station to M30/31 Switchbox

Geological and Groundwater Conditions

Date 14/12/2014

DORA
SAUDI BINLADIN GROUP
HBK
JOINT VENTURE
GREEN LINE UNDERGROUND

Localização das cavidades - Implicações na Escavação

SCENARIO NO.	GEOLOGICAL SCENARIO	REMARKS	FACE PRESSURE	STEERING	THRUST	TORQUE	RING GROUTING VOLUME	WEIGHT AND WATER	STEERING ADJUST	IMMEDIATE ACTIONS	EFFECT ON TUNNELLING OPERATIONS/ SECONDARY ACTION
I	SOLID GEOLOGY (NO VOIDS) 	Ground as per Geotechnical Interpretive Report (GIR).	As designed and within drive parameter range.	No change.	Thrust remains with normal operating levels. Design thrust is [illegible] kN or ([illegible] kN each shoe).	Torque remains with normal operating levels. Nominal torque for operating = [illegible]	Normal theoretical grout volume is [illegible] per shove. Design grout pressure Max. 1 bar above groundwater pressure.	As per Geotechnical Interpretive Report. Excavation target - calculated value [illegible] **(Note: Belt weight accuracy +/- [illegible])**	No adjustment to steering required.	SOP (Standard Operating Procedures).	Nil.
II	SMALL VOIDS AHEAD/AROUND TBM 	If not identified in the GIR then BEAM should identify.	Reduction/loss of face pressure. Face pressure becomes erratic, fluctuating. Greater amount of conditioner due to loss.	Deviation of line and level of TBM. TBM line and level within +/- [illegible]mm of alignment.	Thrust becomes variable, may fluctuate outside of normal operating parameters.	Reduction of torque outside of normal operating parameters.	Increase in required grout volume outside of normal operating parameters. Decrease in required grout pressure outside of normal operating parameters.	Decrease in weight outside of normal operating parameters. Increase in water.	No adjustment to steering required.	Check.	If in filled will have no real effect on tunnelling. Possible secondary grouting required.
III	LARGE VOID TO SIDE OF TBM 	Possible identification during probing. Possible identification from BEAM at distance. Full scale of void may not appear in BEAM field of view.	Reduction/loss of face pressure. Face pressure becomes erratic, fluctuating. Greater amount of conditioner due to loss.	TBM "Pull" away as void. TBM line and level between [illegible] and [illegible]mm of alignment.	Reduction of thrust to one side of TBM, outside of normal operating parameters. Reduction in thrust indicative of which side void is on.	Reduction of torque outside of normal operating parameters. Torque becomes erratic.	Increase in required grout volume outside of normal operating parameters. Decrease in required grout pressure outside of normal operating parameters.	Decrease in Weight outside of normal operating parameters. Increase in Water. Possible in-rush of water.	Reduce speed. Recover slowly.	Slow and adjust steering, [illegible] control.	Further investigation by secondary drilling/grouting. Steering adjust to suit rail alignment.
IV	LARGE VOID ABOVE TBM 	Possible identification during probing. Possible identification from BEAM at distance. Full scale of void may not appear in BEAM field of view.	Reduction/loss of face pressure. Face pressure becomes erratic, fluctuating. Possible decrease due to lower pressure above/ connectivity. Greater amount of conditioner due to loss.	TBM "Pulls" up into void. TBM line and level between [illegible] and [illegible]mm of alignment.	Reduction of thrust on upper side of TBM, outside of normal operating parameters.	Reduction of torque outside of normal operating parameters. Torque becomes erratic.	Increase in required grout volume outside of normal operating parameters. Decrease in required grout pressure outside of normal operating parameters.	Decrease in weight outside of normal operating parameters. Increase in water. Possible in-rush of water.	Reduce speed. Recover slowly.	Slow and adjust steering, [illegible] control.	Further investigation by secondary drilling/grouting. Steering adjust to suit rail alignment.
V	LARGE VOID AT INVERT OF TBM 	Possible identification from BEAM at distance. Full scale of void may not in BEAM field of view.	Reduction/loss of face pressure. Face pressure becomes erratic, fluctuating. Possible increase in face pressure due to higher water pressure.	"Drop" down into void. TBM Line and level outside of [illegible]mm As alignment.	Reduction of thrust on lower part of TBM, outside of normal operating parameters.	Reduction of torque outside of normal operating parameters. Torque becomes erratic.	Increase in required grout volume outside of normal operating parameters. Decrease in required grout pressure outside of normal operating parameters.	Decrease in weight outside of normal operating parameters. Increase in Water. Possible in-rush of water.	STOP	STOP	Further investigation by secondary drilling/grouting. Steering adjust to suit rail alignment.
VI	LARGE VOID BELOW TBM 	Void may not in BEAM field of view. Brittle failure of ground between TBM and void during TBM advance.	Face pressure as designed and within drive parameter range.	Sudden movement down. TBM Line of level outside of [illegible]mm As alignment.	Rapid decrease in thrust.	Torque becomes erratic.	Required grout volume remains within normal parameters. ([illegible]/shove)	Weight remains with normal parameters. Possible increase in water.	STOP	STOP	Possible lining remediation works required. Ground treatment and further investigation in vicinity.
VII	LARGE VOID > DIAMETER OF TBM 	Possible identification during probing. Possible identification from BEAM at distance. Full scale of void may not appear in BEAM field of view.	Face pressure falls off rapidly to zero/reduced groundwater pressure.	Sudden movement down/across. TBM Line and level outside of [illegible]mm As alignment.	ZERO thrust.	Nil.	Increase in required grout volume outside of normal operating parameters. Decrease in required grout pressure outside of normal operating parameters.	Decrease in weight outside of normal operating parameters. Increase in water. Possible in-rush of groundwater.	STOP	STOP	Possible lining remediation works required. Ground treatment and further investigation in vicinity.
VIII	"CRITICAL" VOID CASE- VOID OUTSIDE TUNNEL ALIGNMENT 	Ground as per Geotechnical Interpretive Report (GIR). Void not identified during probing. Void outside BEAM field of view.	As designed and within drive parameter range.	No change.	Thrust remains with normal operating levels.	Torque remains with normal operating levels.	Normal theoretical grout volume is [illegible] per shove.	As per Geotechnical Interpretive Report.	No adjustment to steering required.	STOP	Deflection of lining after TBM moves forward. Lining moves, gaskets leak. Shearing of bolt pockets.




Table1. Advantages of tunnel boring.

Feature	D•B	TBM
Stability		Mechanical solutions for temporary stabilisation of: The face area Around work area The tunnel behind the work area
Shape	Any shape is possible; however, overbreak is inevitable	Naturally stable Ideal for: mass transit, pilot tunnelling, unlined hydro and water conveyance tunnels Superior flow characteristics may eliminate lining requirement
Overbreak		Nearly total elimination of overbreak
Support		Tunnel support may be reduced by 90%
Operating	Very cyclic; dangerous and unpleasant working environment	Continuous (non-cyclic), repetitive operation; safer and more pleasant working environment than in D+B
Blasting	Increased support requirement Increased water inflow Increased overbreak	
Overbreak	Costly filling with concrete	Eliminated
Support		Mechanical solutions available for stability and temporary support at the face, work area, and permanently behind the excavation operation
Crews	All skills required	Consistent, repetitive, less skilled, and easily trained operations (labour is assigned to limited tasks that are repetitive, become routine, and may even produce competition among the labourers
Access structure	Shafts and adits necessary to open multiple headings;	Can eliminate all temporary access structures, particularly if the project is well laid out

Earth Pressure Balance (EPB) TBM

This is a mechanised tunnelling method in which spoil is admitted into the tunnel boring machine (TBM) via a screw conveyor arrangement which allows the pressure at the face of the TBM to remain balanced without the use of slurry.

Advantages

- Allows soft, wet, or unstable ground to be tunnelled with a speed and safety not previously possible
- Limits ground settlement and produces a smooth tunnel wall. This significantly reduces the cost of lining the tunnel, and makes it suitable to use in heavily urbanized areas

Disadvantages

- The major disadvantage is the upfront capital cost. TBMs are expensive to construct, difficult to transport, require significant backup systems and power.

Main characteristics

- Tunnel Lining – Precast Concrete Segments
- Typical Performance - 9m to 35m per day. Actual performance and costs will depend on ground conditions and tunnel diameter.
- Typical Costs – USD 6,460 to USD 42,760 per metre

Table 1: Advantages and disadvantages of tunnel construction methods

Method	Advantages	Disadvantages	References
Drill & Blast	Very adaptable and flexible Short mobilization time requirement Any required shape tunnel cross section is possible Primary rock support can be installed Total investment cost is less Tunnel shape can be changed along the drive length	Safety of workers is a serious issue Performance rate of advance excavation is lower Total labor cost is high Involvement of hard and high manual labor Low level of automation and mechanization of tasks	(Girmscheid and Schexnayder 2002)
TBM	Very high performance and low labor costs High progress rate, especially in soft ground soil Excellent cost efficiency and high automation level Continuous operation Less noise and disturbance to surrounding structures Best way for constructing deep and long tunnels	Limited flexibility in response to extremes of geologic conditions High investment costs and require high backup systems TBM mobilization take considerable time Fixed circular geometry and tunnel diameter Longer mobilization time and higher capital costs	(Girmscheid and Schexnayder 2002, Abdallah and Marzouk 2013)

Obrigado pela Atenção