FREJUS HIGHWAY TUNNEL

Presented by Magali SCHIVRE , **Systra**

Client

Project Manager

Constructor

OUTLINE

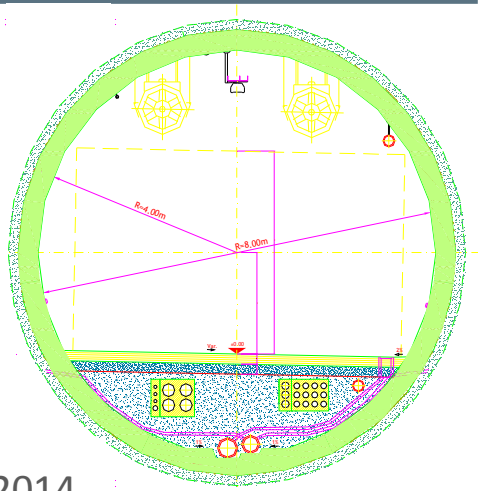
1. General Overview
2. Specific geological context
3. Specific design of a hard rock single shield TBM suited for high deformable rocks
4. Knowledge acquired during the construction
5. Conclusions

1.

GENERAL OVERVIEW

SYSTRA

A second tube for the Frejus Highway tunnel

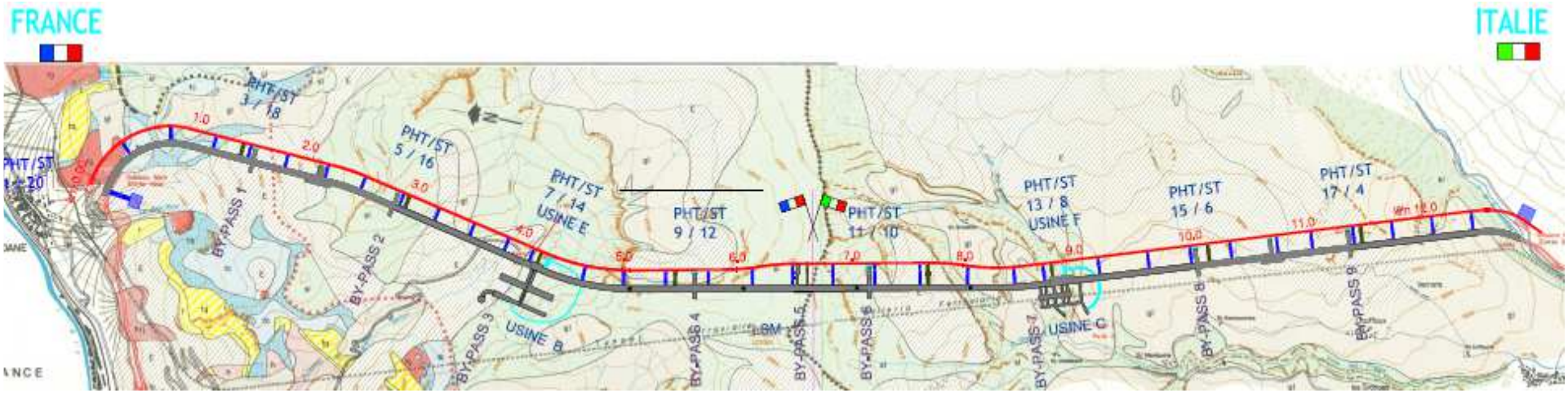


Improve the level of safety with a second tube :

- L≈13km, $Ø_{utile\ inside}$ 8,00m (8,20m inside),
- 34 by-pass = “safe area”
- 5 by-pass for vehicles

Current progression

- Work started in December 2009
- TBM started on 5th July 2011, at PM 654 - Ended on the 17th November 2014
- End of civil works in 2017



SYSTRA

PROJECT COSTS & ACTORS

Total Project Cost is about 400 M€ , shared between France & Italy (GC 250M€, equipment 50M€, others 100M€)

Main ACTORS:

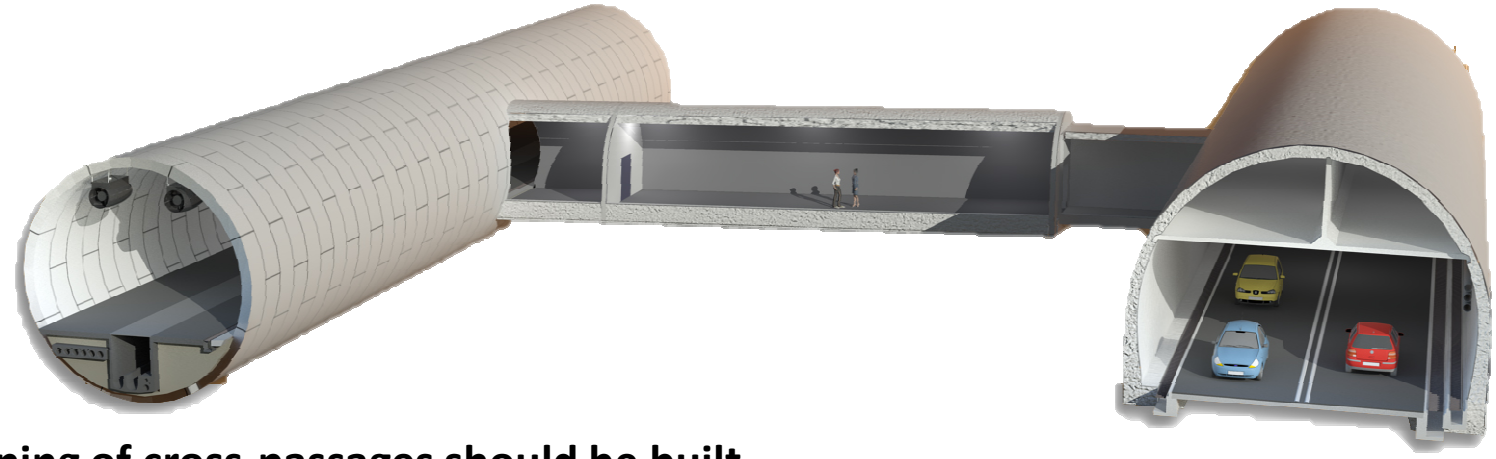
- 2 Clients: SFTRF, SITAF
  1 Operator: GEF

- Project Manager: I3S (SYSTRA mandatory, SWS et SEA)

- Contractor Joint Venture :
  Lot 1 (French side): RAZEL - BILFINGER

  Lot 2 (Italian side): ITINERA - RAZEL

SPECIFIC CONSTRAINTS



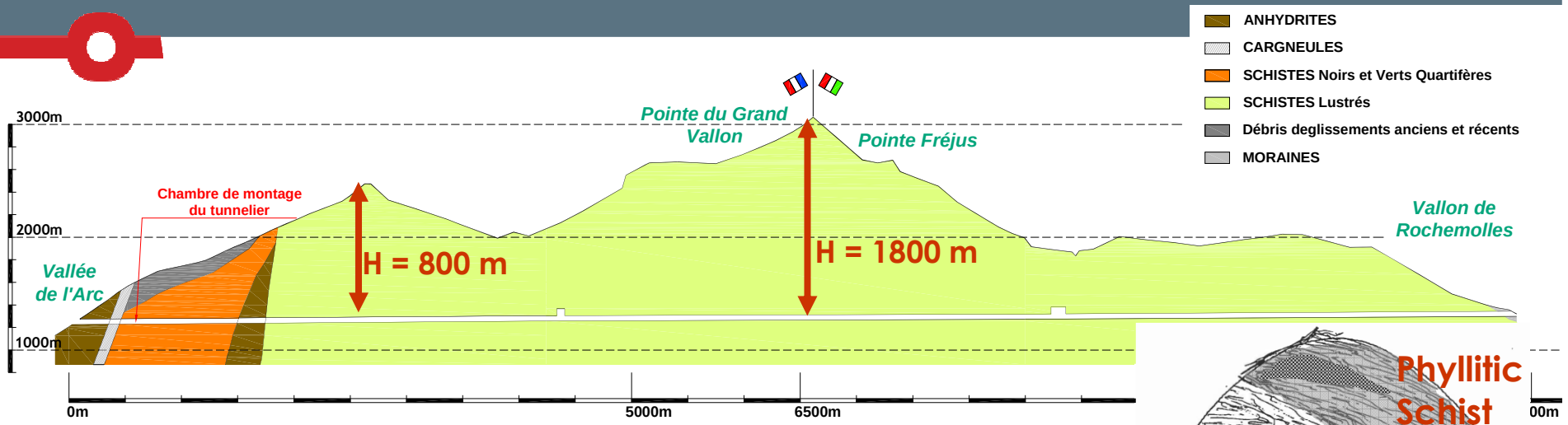
The opening of cross-passages should be built near the back of the machine, and activated for operation progressively

- Opening of the last by-pass at a maximum distance of **1000m** from the TBM
- The by-pass must be operational not later than **4 months** after the TBM excavation

2

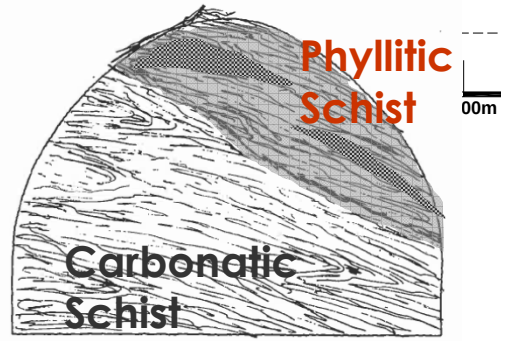
SPECIFIC GEOLOGICAL CONTEXT

GEOLOGICAL & GEOMECHANICAL CONTEXT



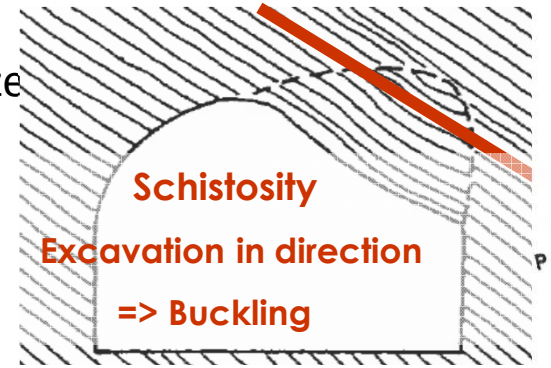
High overburden from 800 to 1800 m

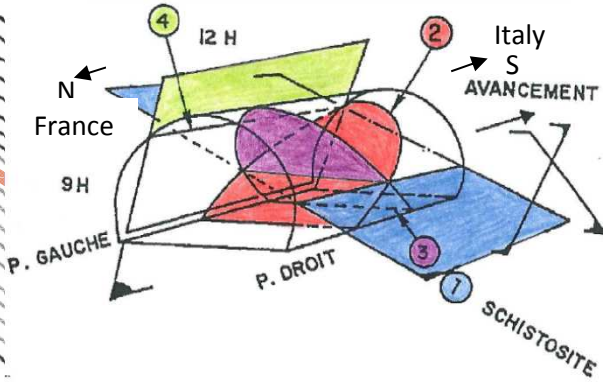
From Triassic series (Anhydrite, Chert, Quartz, Black and Green Schist) & through the calc-schist formation (*schistes lustrés)*



The Calc-schist rock mass is characterize

- Anisotropy of composition
- Anisotropy due to schistosity
- Anisotropy of stress field σ_H= 1.2 to 1.4 σ_V





SYSTRA

FREJUS HIGHWAY TUNNEL BUILT FROM 1974 TO 1979

Highway tunnel // new gallery (Inter-axis = 50 m)

Issues started at the beginning of the Calc-schist formation

Drill & Blast methods, flexible support (bolts density : 1,2 u/m²)

- **Convergence up to 45cm** (Schist buckling + Squeezing phenomena)
- Development of a **plastic zone up to 10m** around the excavation
- High stress level ; Very high loads on the support, Rupture & Shearing of the bolts

3.

Design of a Single Shield TBM *suited for highly deformable rocks*

SYSTRA

An adaptable TBM with the following requirements

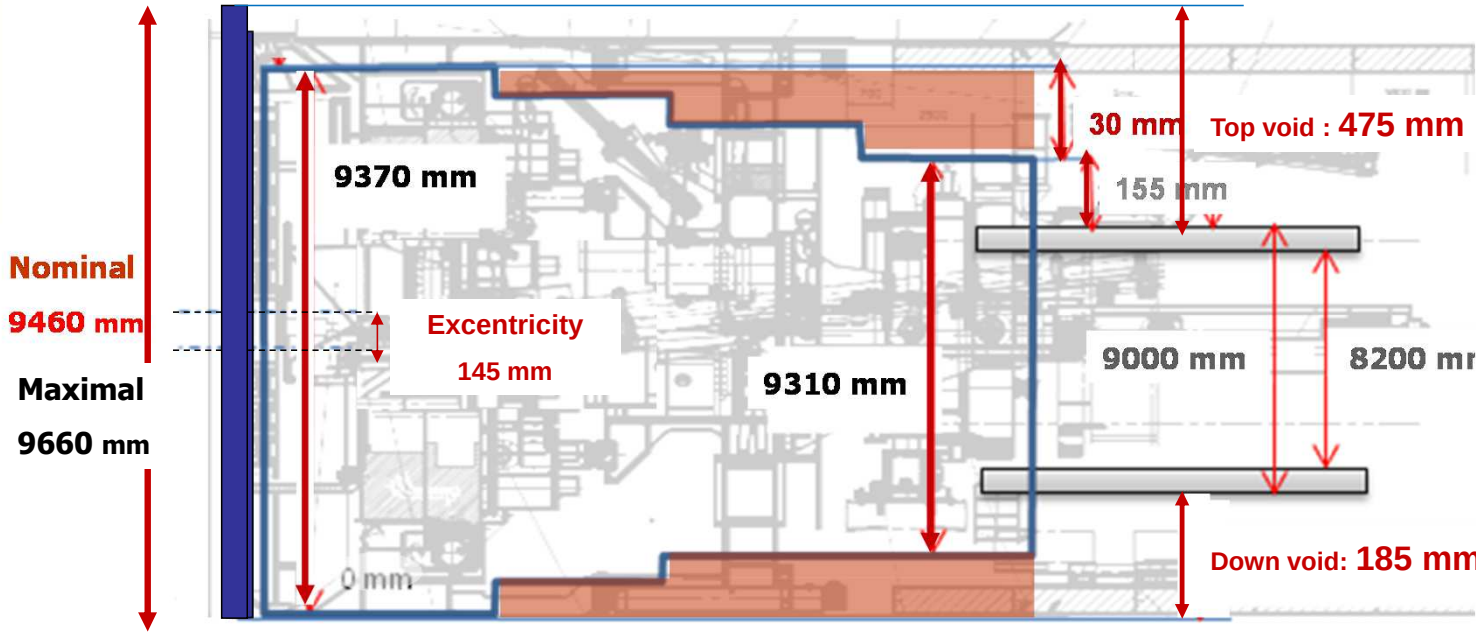
A hard rock single shield TBM, suited for highly deformable rocks:

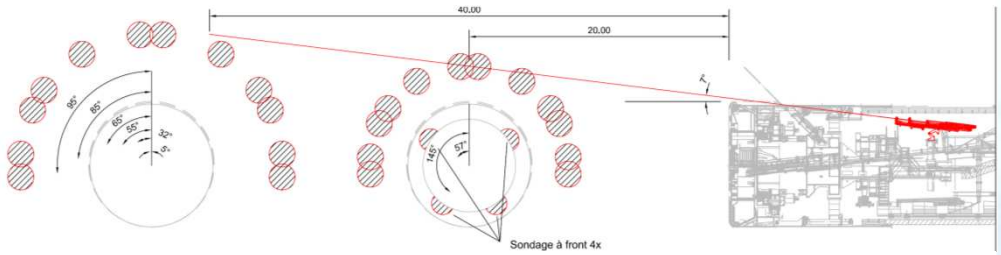
- Short single shield ***Length = 11.20 m ; Cutterhead diameter*** **9,46 m**
- High breakaway Thrust ***Total Breakaway Thrust 106 160 kN ; Breakaway Torque 21 289 kNm***
- Reinforced Shield

To allow some convergences and to limit the extension of the plastic zone

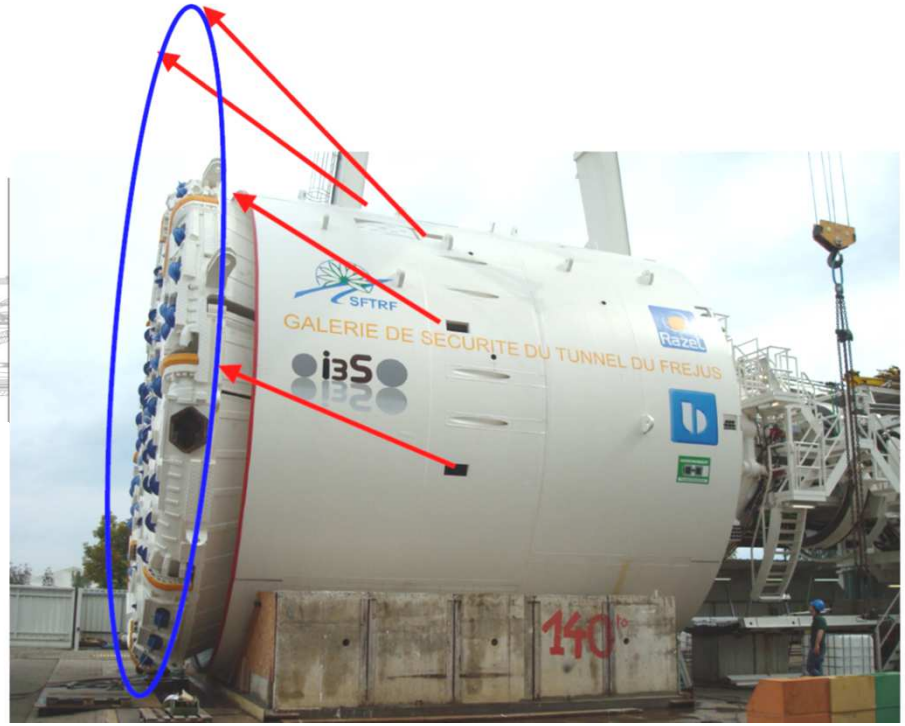
- **High Shield conicity** ***60 mm on diameter***
- **Big annular void**
- Possibility to **increase the boring diameter**
- Possibility of **bolting** from the shield
- Possibility of ***probe drilling survey*** *at the front*

An adaptabl





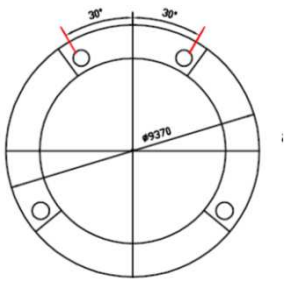
12 openings on the shield
4 position in the front, 2 opening in the cutterhead




SFTRF
Razel
09/05/2011 11:01

TBM EQUIPMENT – *Gap around the shield mesuring*

10 hydraulic jacks to mesure the gap around the shield



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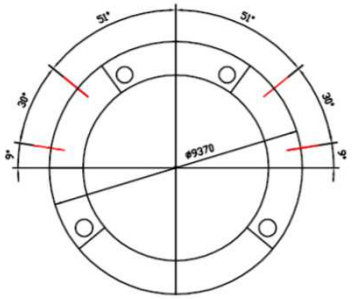

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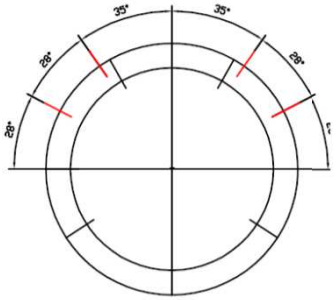

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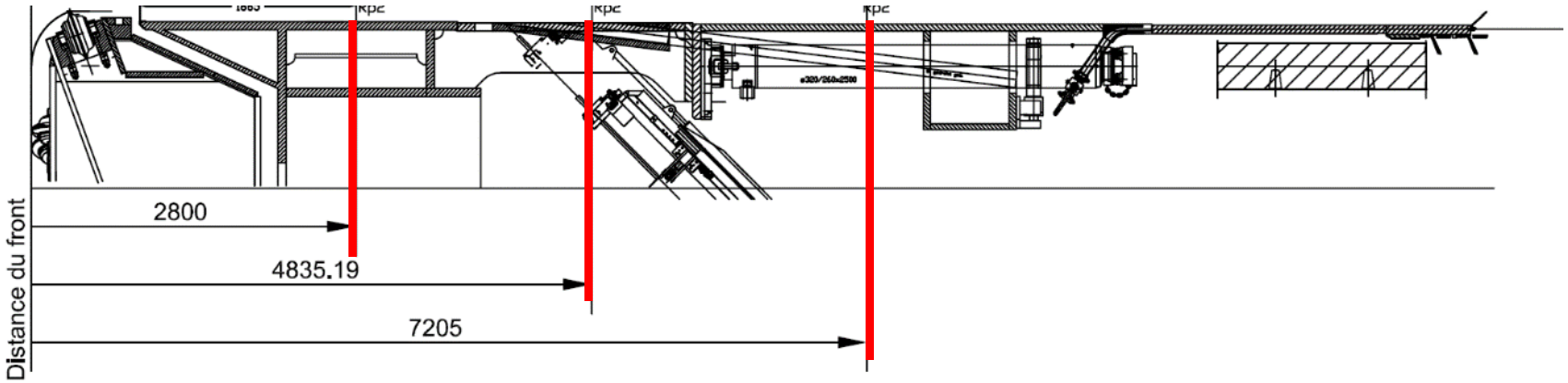


SYSTRA

SEGMENT LINING

Adapted dimensioning of the segments lining and their framework Universal Ring

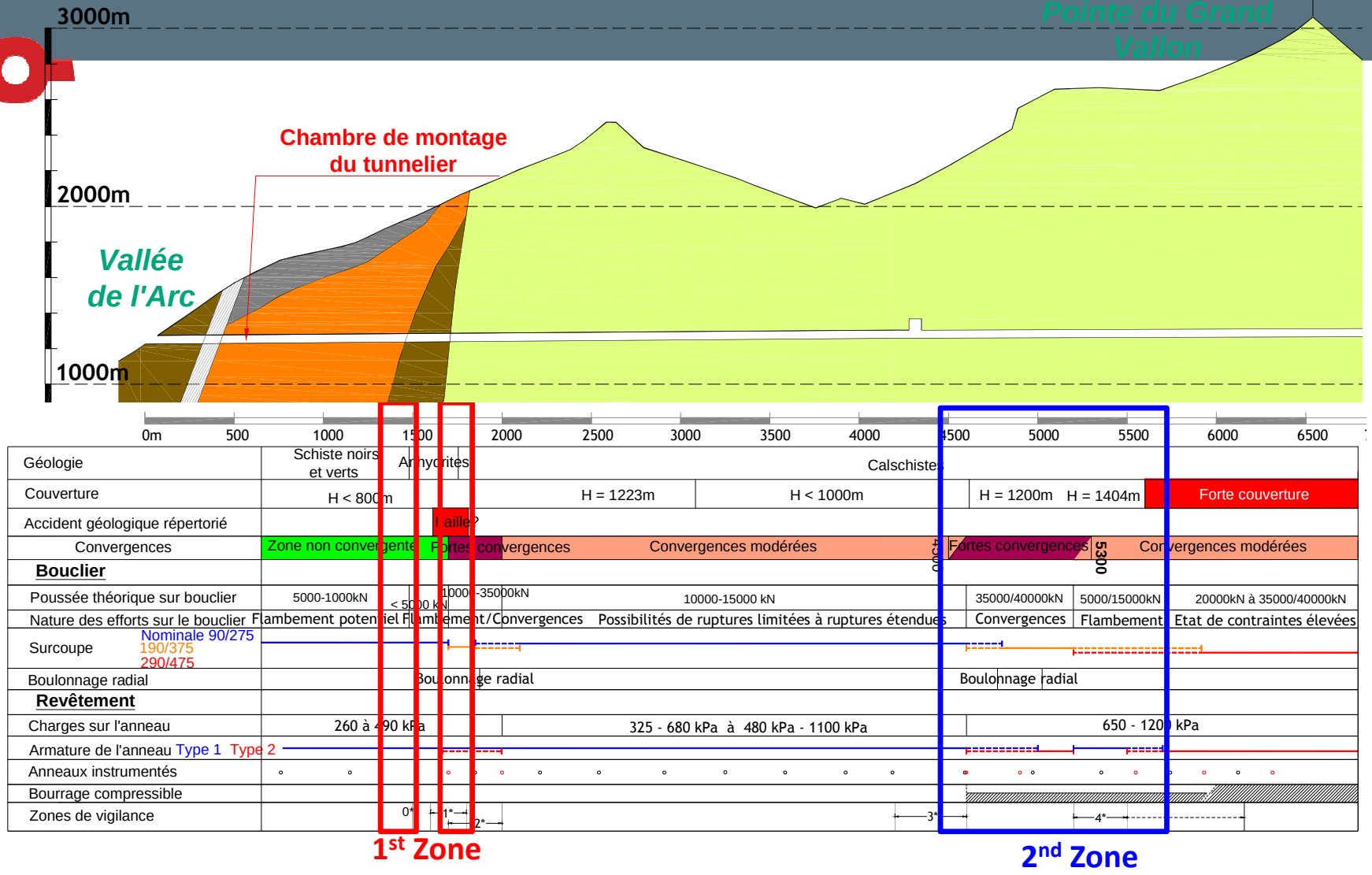
Ring Division:	6+1
Segment Length:	1800 mm
Segment Inner Diameter:	8200 mm
Segment Outer Diameter:	9000 mm

Two types of segments :

- *Type 1: C35/45 - 80 kg/m3 steel ratio -* 2 SOF-Clips
- *Type 2: C35/45 - 125 kg/m3 steel ratio -* 2 x2 SOF-Clips

SYSTRA

INITIAL MODEL OF Advancement Plan for the TBM



SYSTRA

4.

Knowledge acquired during the construction

A learning method, utilizing anticipation, retroanalysis

*As for conventional method, a team of engineers was dedicated to the **follow up** excavation parameters and able to decide to set up adaptation on TBM, taking into account the industrial process of TBM advancement*

Actions implemented to follow the construction and anticipate problems :

- **Follow up of the construction with Systematic analysis , with Threshold values calibration**

- **Set up TBM adaptations or countermeasures**

Follow up of the construction & Monitoring

TBM Parameters follow up

Geological investigation:

- Systematic probe drilling survey
- Radial Boreholes
- Analysis of the annular void (openings, endoscope)

LINING Follow up :

- Strains gauges in the lining
- In-situ stress measure
- Deformation measures

Date :	16/11/2011	Anneaux	525	à	531

Paramètres étudiés	U	Seuil de vigilance			Seuil d'alerte			16/11/2011			15/11/2011	Comparaison J / J-1
			mini	max		mini	max	Valeur mini du jour J	Valeur maxi du jour J	Moyenne de J	Moyenne de J-1	% variation
Verin R1	mm	< >	80	200	< >	50	300	109	149	**129**	*106*	**21%**
Verin R2	mm	< >	80	200	< >	50	300	35	147	**107**	*22*	**379%**
Verin R3	mm	< >	80	200	< >	50	300	73	140	**119**	*119*	**0%**
Verin R4	mm	< >	80	200	< >	50	300	73	129	**110**	*111*	**-1%**
Verin R5	mm	< >	80	200	< >	50	300	101	144	**118**	*121*	**-3%**
Verin L1	mm	< >	80	200	< >	50	300	137	188	**165**	*159*	**4%**
Verin L2	mm	< >	80	200	< >	50	300	159	179	**169**	*160*	**6%**
Verin L3	mm	< >	80	200	< >	50	300	152	187	**171**	*161*	**6%**
Verin L4	mm	< >	80	200	< >	50	300	159	175	**167**	*158*	**5%**
Verin L5	mm	< >	80	200	< >	50	300	151	164	**159**	*152*	**4%**
Force de poussée totale	KN	>	30 000		>	35 000		19 000	29 900	**23 986**	*25 664*	**-7%**
Force de frottement	kN	>	10 000		>	12 500		10 000	13 800	**11 743**	*14 927*	**-21%**
Force de poussée sur le terrain	kN	<	10 000		<	8 000		9 800	15 800	**12 400**	*11 082*	**12%**
Poids de marinage	T	>	210		>	220		185	203	**193**	*203*	**-5%**
Vitesse de creusement	mm/min	>	60		>	75		64	84	**77**	*71*	**8%**

<	Seuil mini
>	Seuil maxi

	Alerte
	Vigilance
	OK

Follow up of the construction & Monitoring

- **TBM Parameters follow up**

- **Geological investigation:**
  - Systematic probe drilling survey
  - Radial Boreholes
  - Analysis of the annular void (openings, endoscope)

- **LINING Follow up :**
  - Strains gauges in the lining
  - In-situ stress measure
  - Deformation measures

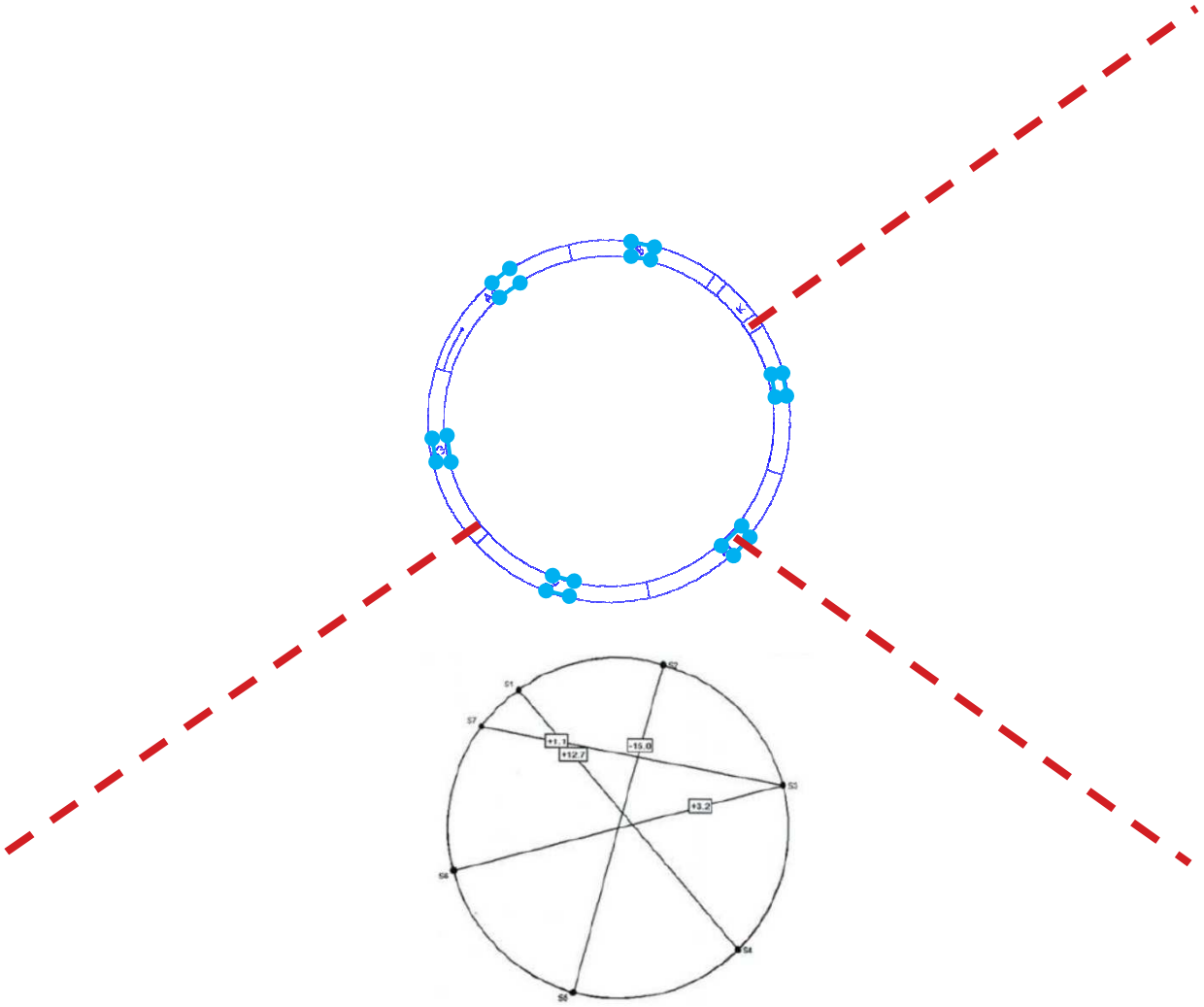
Carottage radial

Annular void

Shield windows

Follow up of the construction & Monitoring

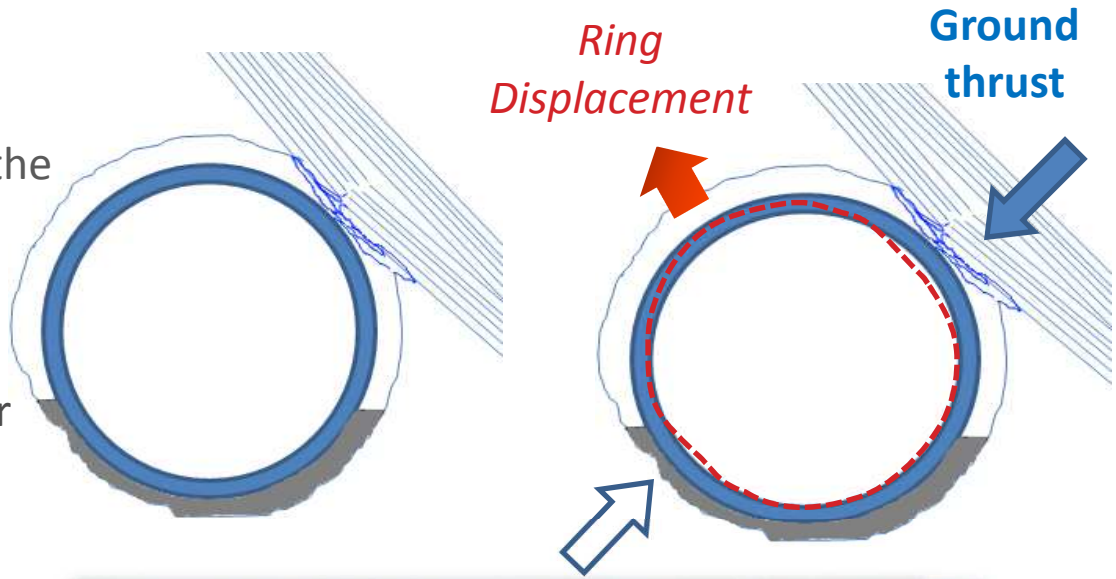
- **TBM Parameters follow up**
- **Geological investigation:**
  - Systematic probe drilling survey
  - Radial Boreholes
  - Analysis of the annular void (openings, endoscope)
- **LINING Follow up :**
  - Strains gauges in the lining
  - In-situ stress measure
  - Deformation measures



Buckling phenomena - First zone

Observed behaviour :

- Buckling caused rock contact against the shield and the segment lining, on the right side of the gallery
- Issues to fill the annular void
- A very dense schistosity, RQD =0, poor rock mass quality



Consequences:

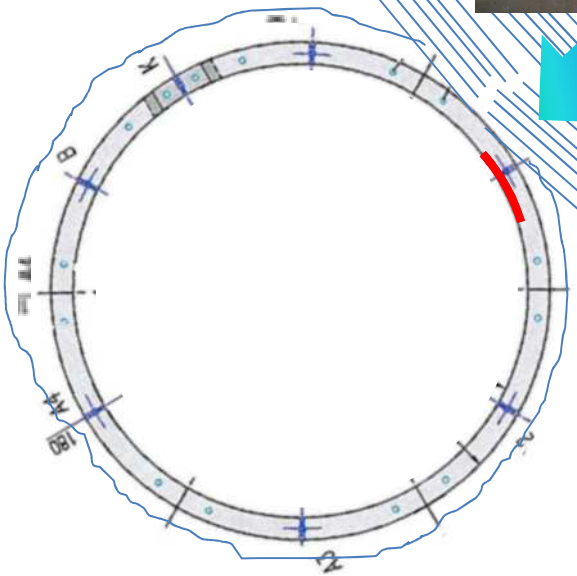
- Very localized load (L=2m) => asymmetric loading
- Lack of abutment leads to ring displacement
- Significant cracks on segment lining

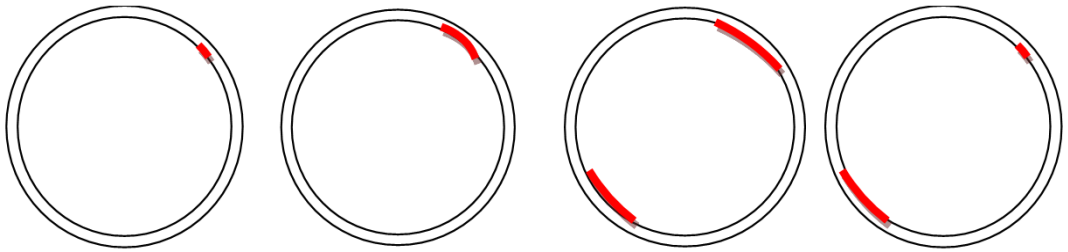
SYSTRA

Buckling phenomena, around PM 1500

Consequences of buckling :

- Occurrence of cracks on segment lining (*1mm to 2mm*)





- Odd rings: **opening joints + offset**
- Even rings: **cracks (1mm to 2mm)**

SYSTRA

Counter-measures during excavation

First zone of convergences (PM 1 180 – 2 980)

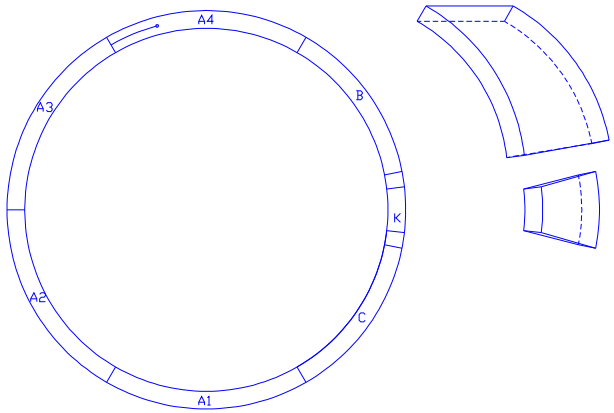
- Non-expected zone
- Very high Thrust(50 000kN)
- Low values of the hydraulic jacks on right side

Counter-Measures implemented

Second Type of segments

(*125 kg/m³ steel ratio)*

2 x2 SOF-Clips

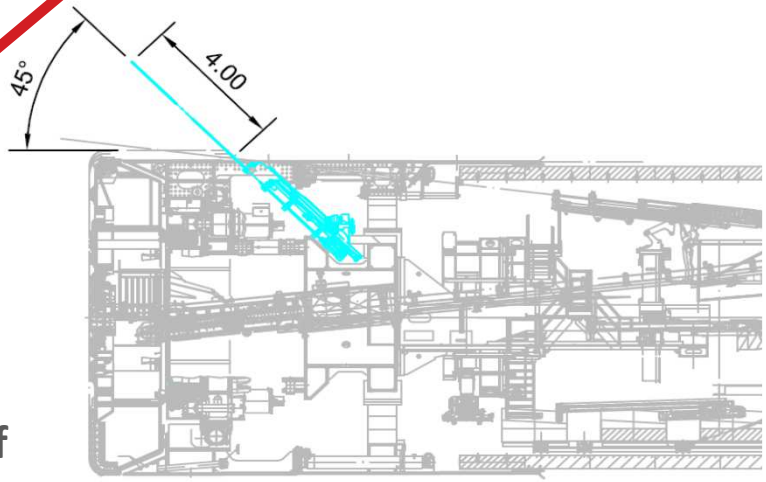


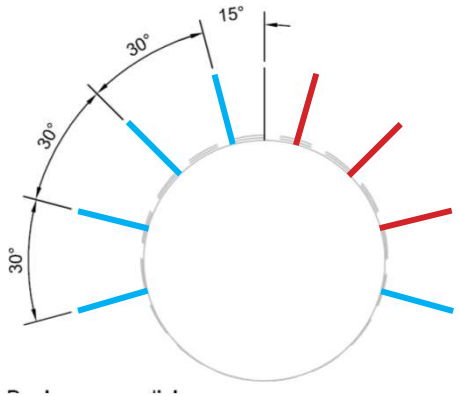
Increase the diameter of excavation

(190mm)

Radial rockbolts

(3 à 9 Swellex, L=4m)



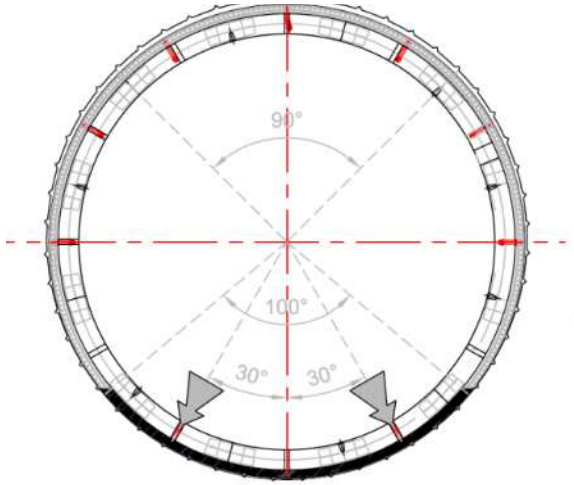


SYSTRA

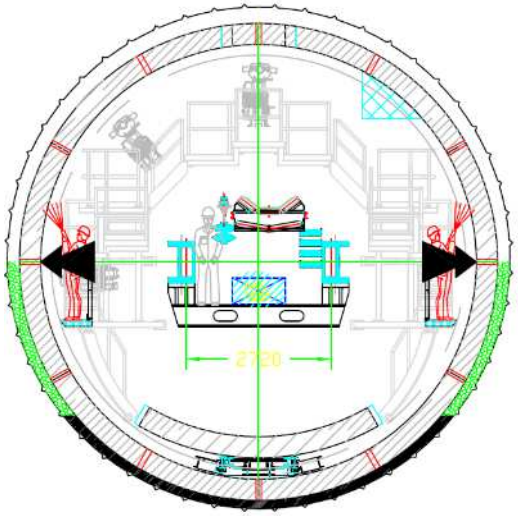
Improvement of the annular void fillling

Initial procedure to fill the annular void

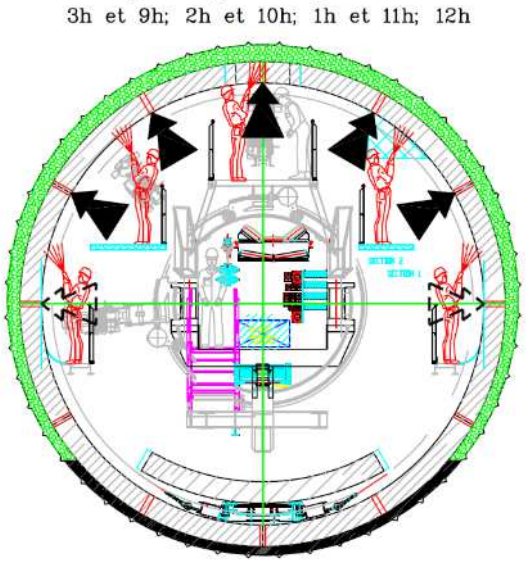
Mortar at the invert
During TBM progress



Ring N-2
Filling with pea gravel



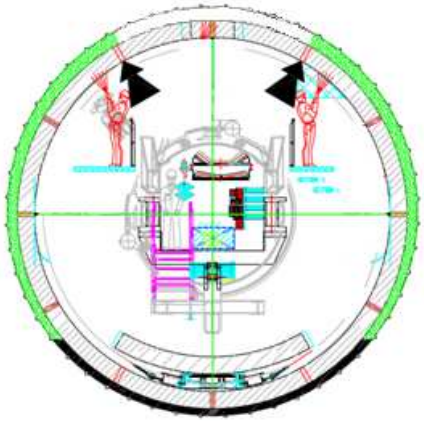
Ring N-5 to N-7
Filling with pea gravel



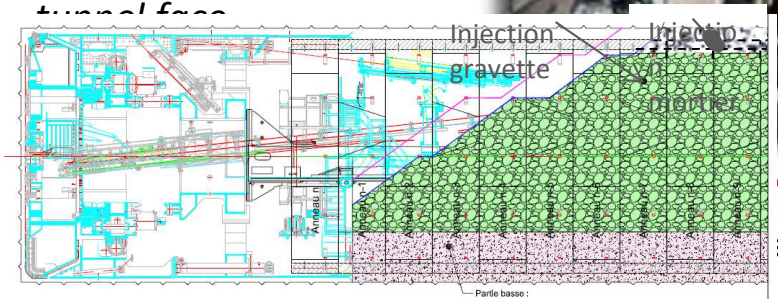
SYSTRA

Improvement of the annular void fillling

Ring N-2
Filling with pea gravel

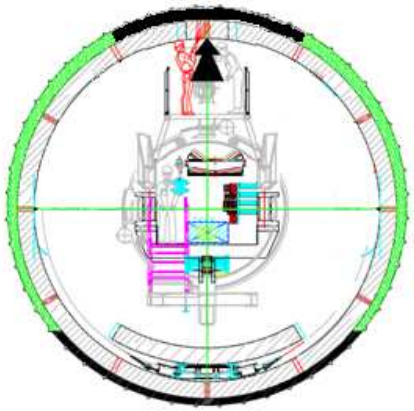


Issues to fill the void with mortar from the tailskin because of the important shield conicity => the mortar flows towards the tunnel face



Filling with pea gravel

Ring N-5 to N-7
Filling with mortar



Filling with mortar at the crown

SYSTRA

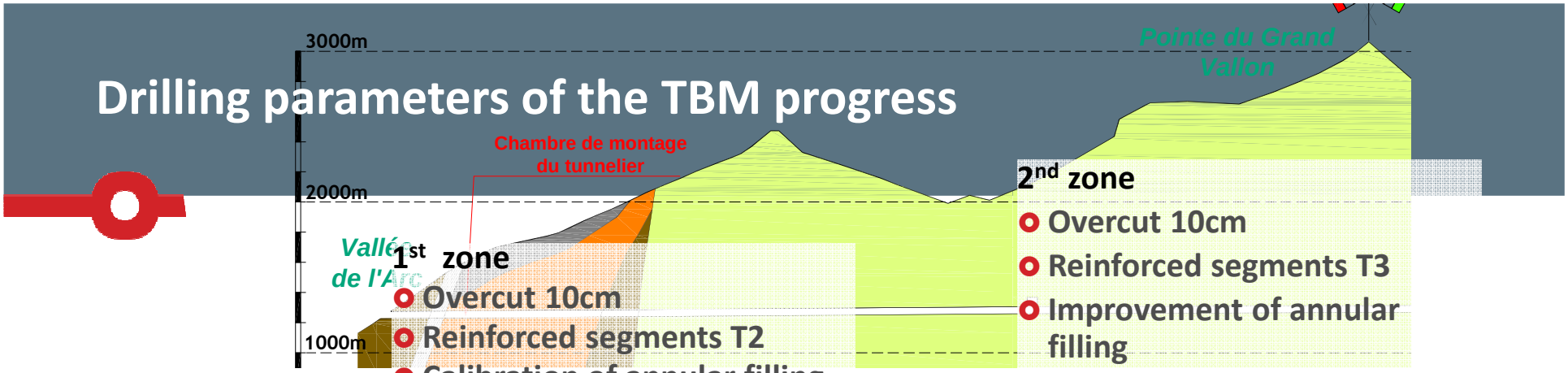
Design & construction of New type of segment T3

Augmentation of the steel ratio of the segments in order to avoid the cracking phenomena

A third type of segments is designed :

- Type 3: C35/45 - **285 kg/m3 steel ratio**
- 2 x2 SOF-Clips with reinforced web

Drilling parameters of the TBM progress

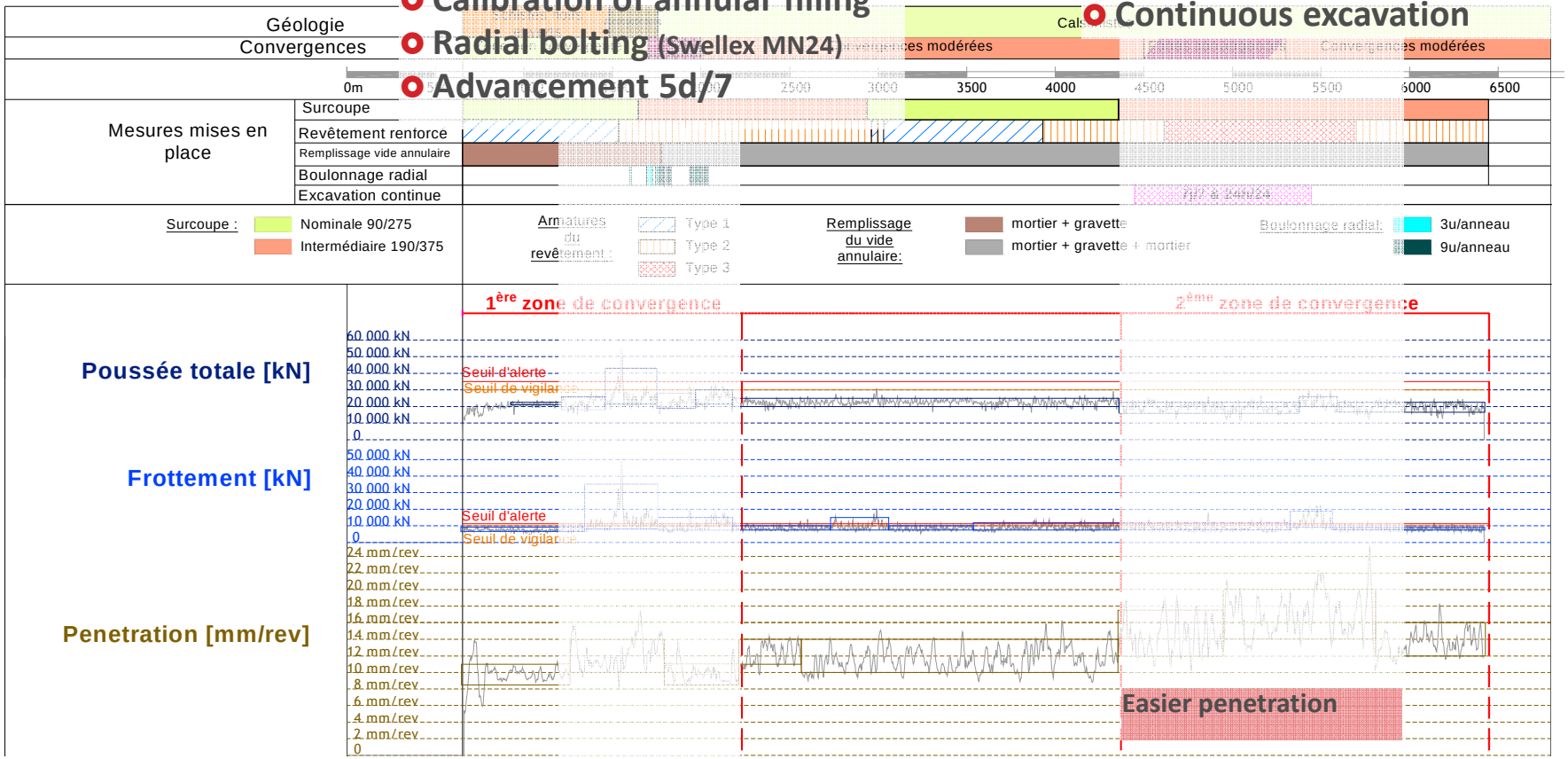


1st zone

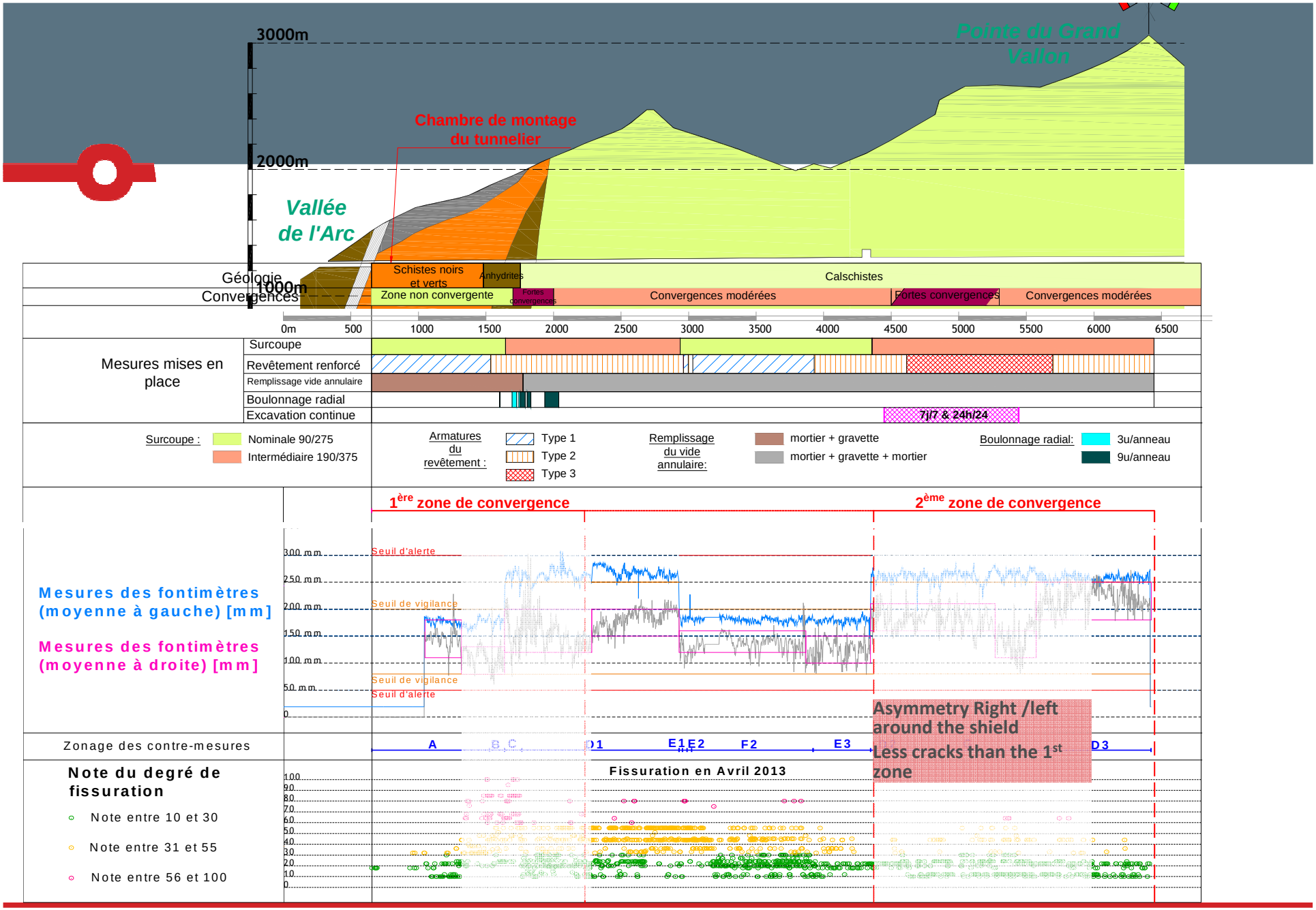
- Overcut 10cm
- Reinforced segments T2
- Calibration of annular filling
- Radial bolting (Swellex MN24)
- Advancement 5d/7

2nd zone

- Overcut 10cm
- Reinforced segments T3
- Improvement of annular filling
- Continuous excavation



SYSTRA


3000m
2000m
1000m
Pointe du Grand Vallon
Chambre de montage du tunnelier
Vallée de l'Arc
Géologie
Convergences
Schistes noirs et verts
Anhydrites
Calschistes
Zone non convergente
Fortes convergences
Convergences modérées
Fortes convergences
Convergences modérées
0m 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500
Mesures mises en place
Surcoupe
Revêtement renforcé
Remplissage vide annulaire
Boulonnage radial
Excavation continue
7j/7 & 24h/24
Surcoupe :
Nominale 90/275
Intermédiaire 190/375
Armatures du revêtement :
Type 1
Type 2
Type 3
Remplissage du vide annulaire:
mortier + gravette
mortier + gravette + mortier
Boulonnage radial:
3u/anneau
9u/anneau
1ère zone de convergence
2ème zone de convergence
Mesures des fontimètres (moyenne à gauche) [mm]
Mesures des fontimètres (moyenne à droite) [mm]
300 mm
250 mm
200 mm
150 mm
100 mm
50 mm
0
Seuil d'alerte
Seuil de vigilance
Seuil de vigilance
Seuil d'alerte
Asymmetry Right /left around the shield
Less cracks than the 1st zone
Zonage des contre-mesures
A
B
C
D1
E1
E2
F2
E3
D3
Note du degré de fissuration
Note entre 10 et 30
Note entre 31 et 55
Note entre 56 et 100
Fissuration en Avril 2013
100
90
80
70
60
50
40
30
20
10
0

5.

CONCLUSIONS

CONCLUSIONS

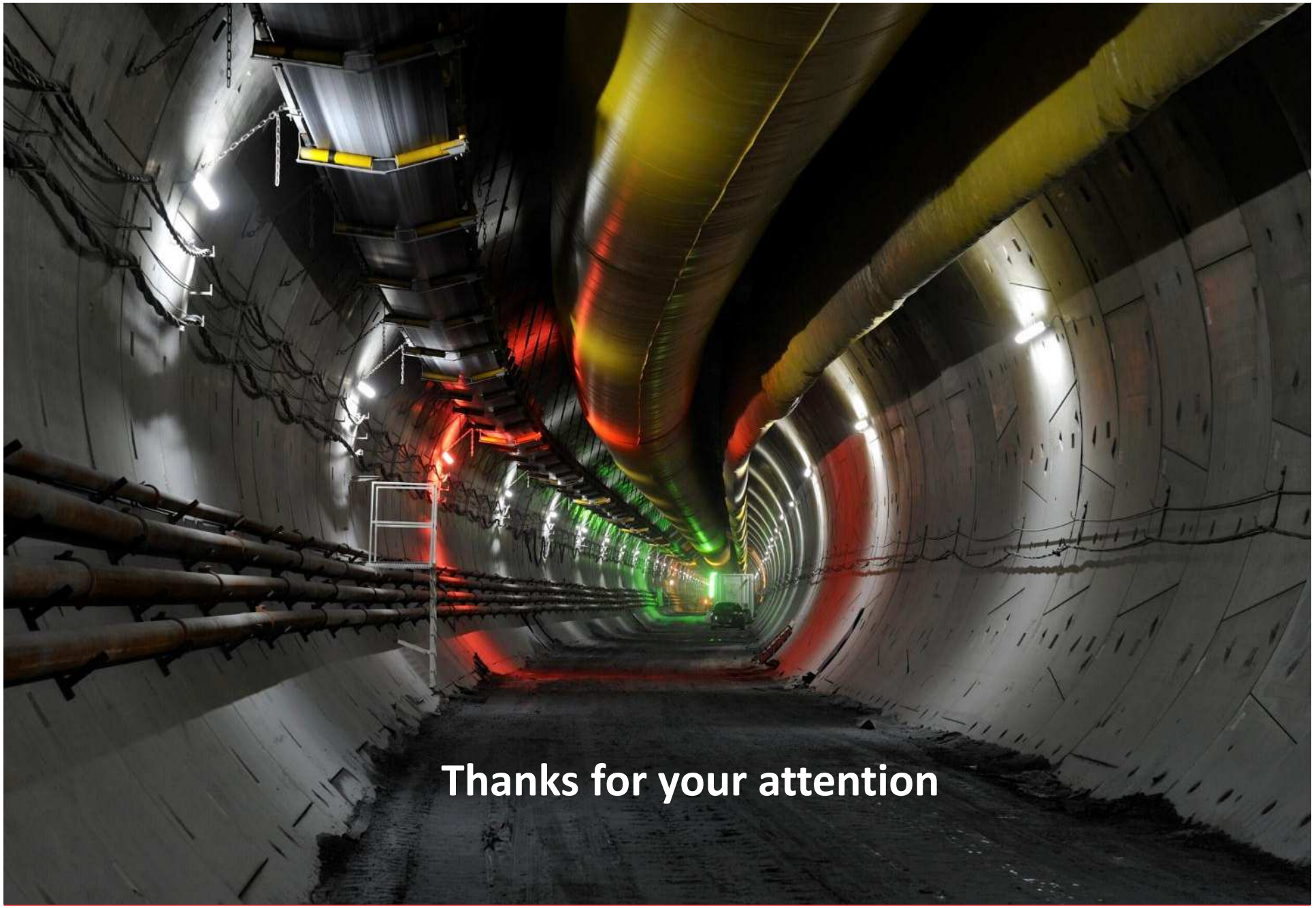
TBM tunnel successfully finished

- A project developed in a well-known geological context, but with a **« new » construction method** in this challenging environment, taking advantage of the knowledge acquired on the first tunnel

- Importance of the quality of the **design of the TBM single shield** *suited for high deformable rocks, and asymmetric deformation,*

- Importance of the **quality of the follow up during construction** in order to anticipate and to be reactive:
  - Skilled team
  - Calibration of threshold values
  - Iterative procedure : need to a continuous link between design studies and works

- An average excavation speed of **400m/month**


Thanks for your attention