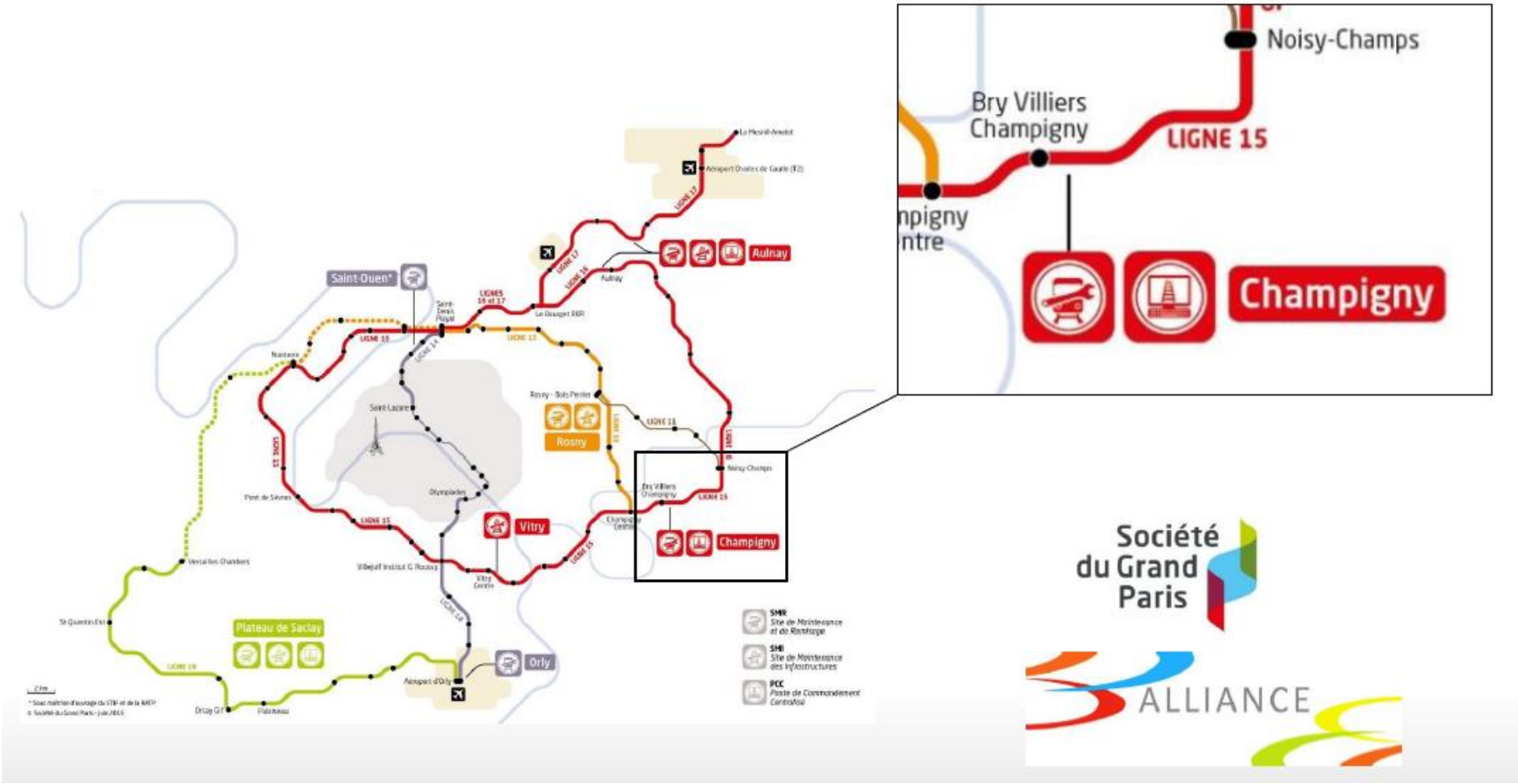
PIZZAROTTI
FONDATA NEL 1910

Tunnelling in Paris: The experience gained on the Gran Paris Metro Line 15 Section C

Massimo Concilia

The Grand Paris Metro Line 15 Section C Project

- The Grand Paris Express Metro Project with approximately 200 km of new automatic metro lines and 68 stations has been designed to link the three major airport of the city as well as business and scientific clusters in the metropolitan region of the city of Paris.

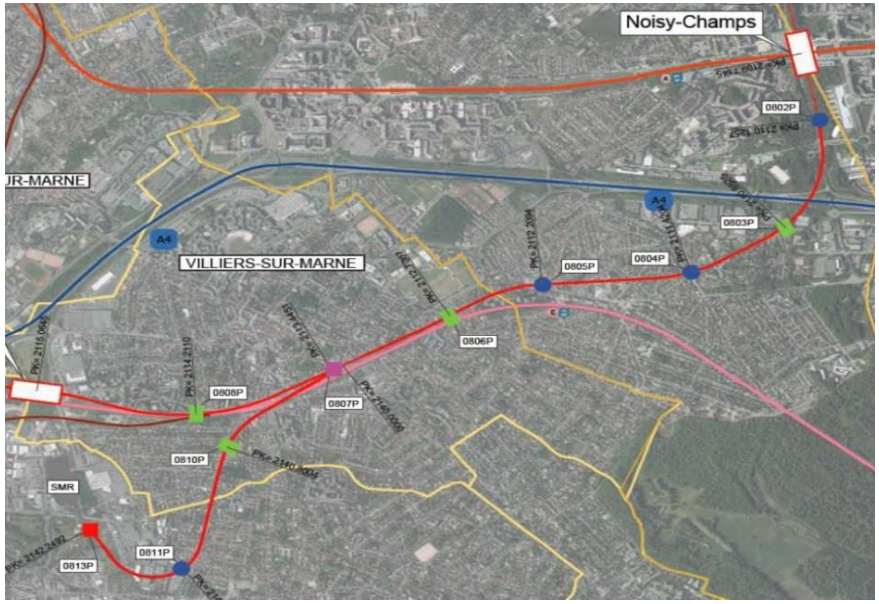


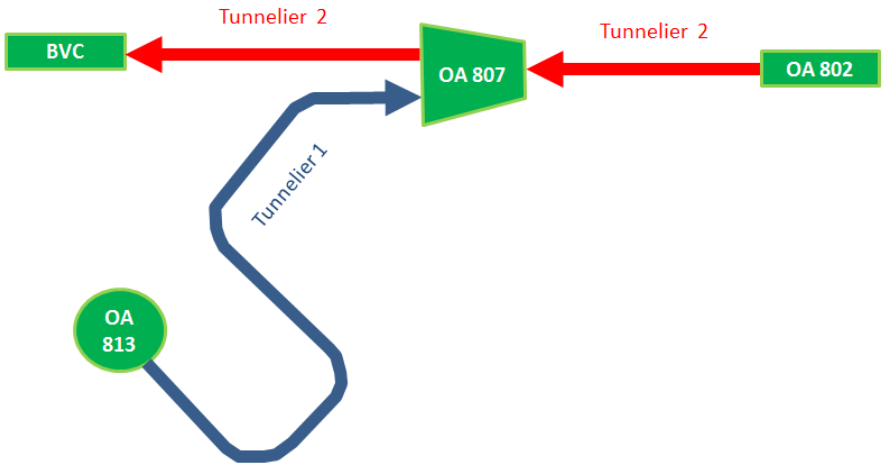
Project description

- Purpose of the Project: Construction of the new Paris Metro Line 15 between Noisy Champs and Bry Villiers Champigny stations.

- Client: Société du Grand Paris
- Contractor: Demathieu Bard – NGE – Pizzarotti – Implenia JV namely ALLIANCE
- Resident Engineer: Systra
- Contractual time and expected completion date: 50 months; November 2020.

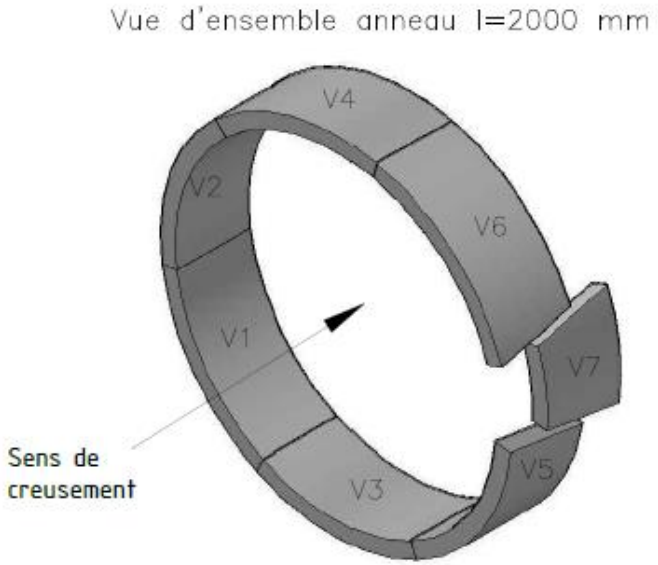
- The Project includes the detailed design and construction of two tunnels and 11 shafts for emergency, ventilation and for operations:
  - Drive 1: OA 813 – OA 807 L=2.159 m
  - Drive 2: OA 802 – BVC L=4.673 m
  - Nominal excavation diam. D=9.860 mm

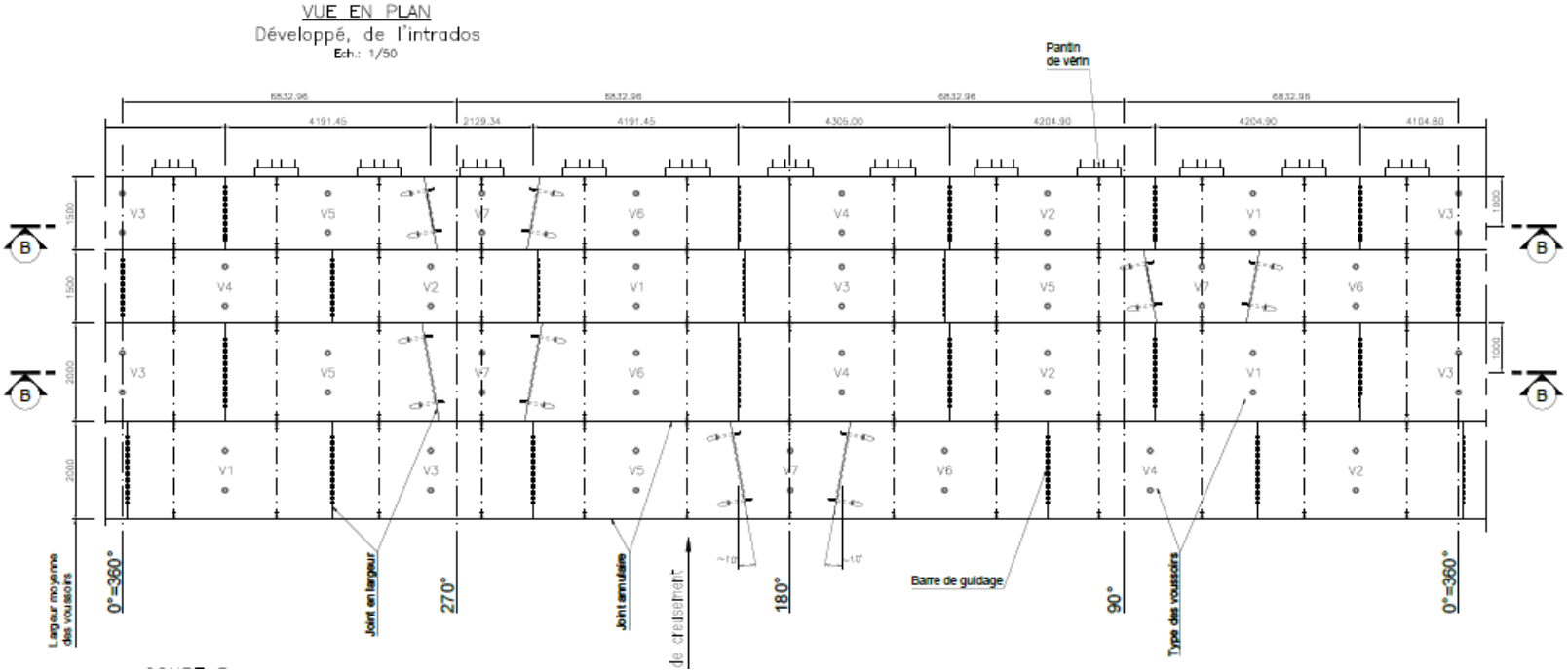




Project description: The tunnel lining

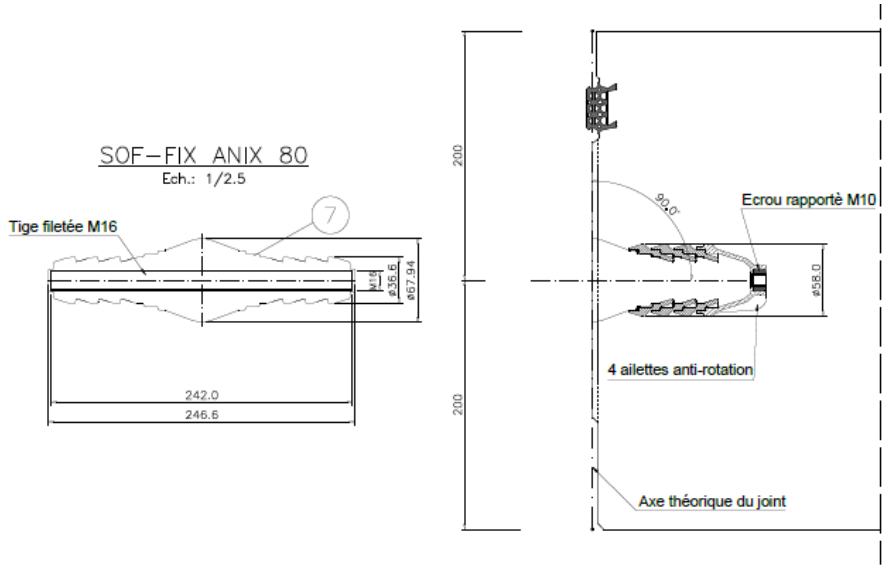
- Lining composed of pre-casted segmental lining Universal type ring: 6 segments + 1 key element
- Ring length: 1.5 m for curves and 2.0 m for straight alignment or curve with R>360 m.
- Thickness: 400 mm
- Internal lining diameter: 8,7 m
- External lining diameter: 9,5 m

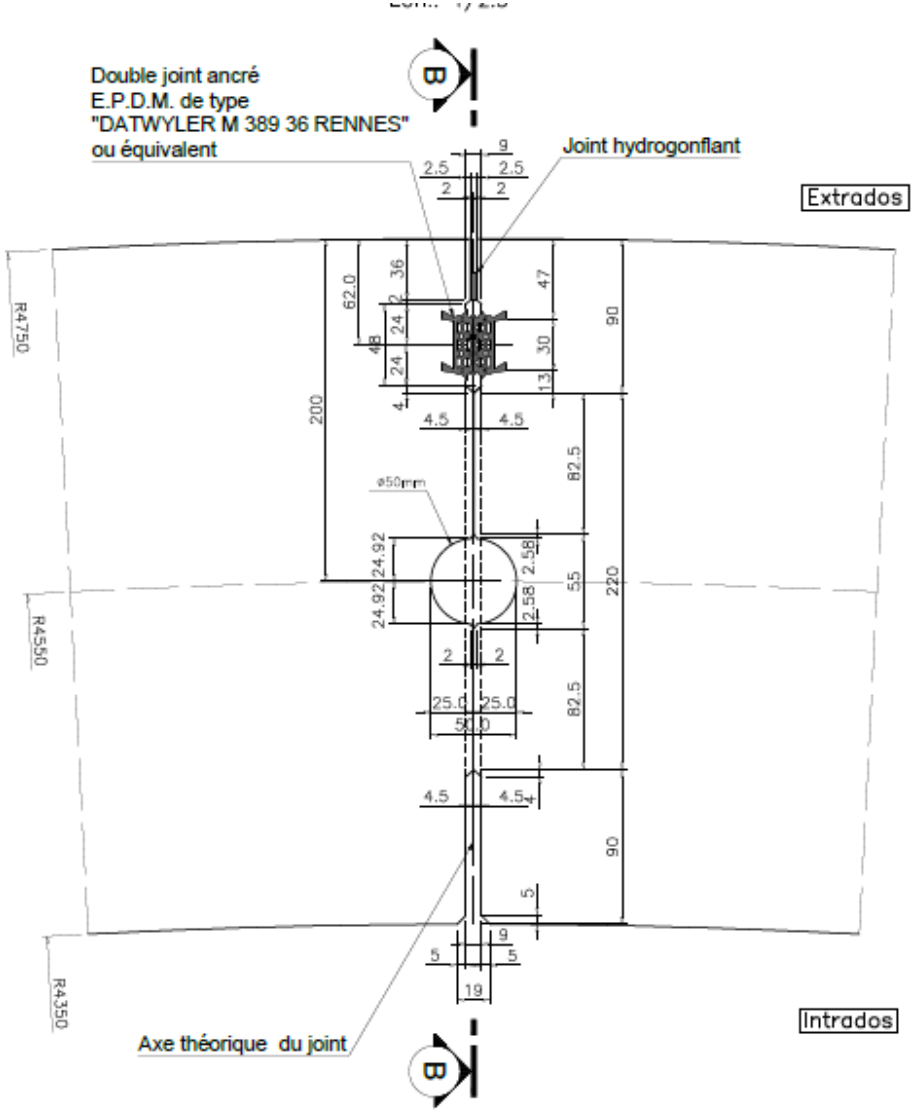




Segmental lining: Joints design

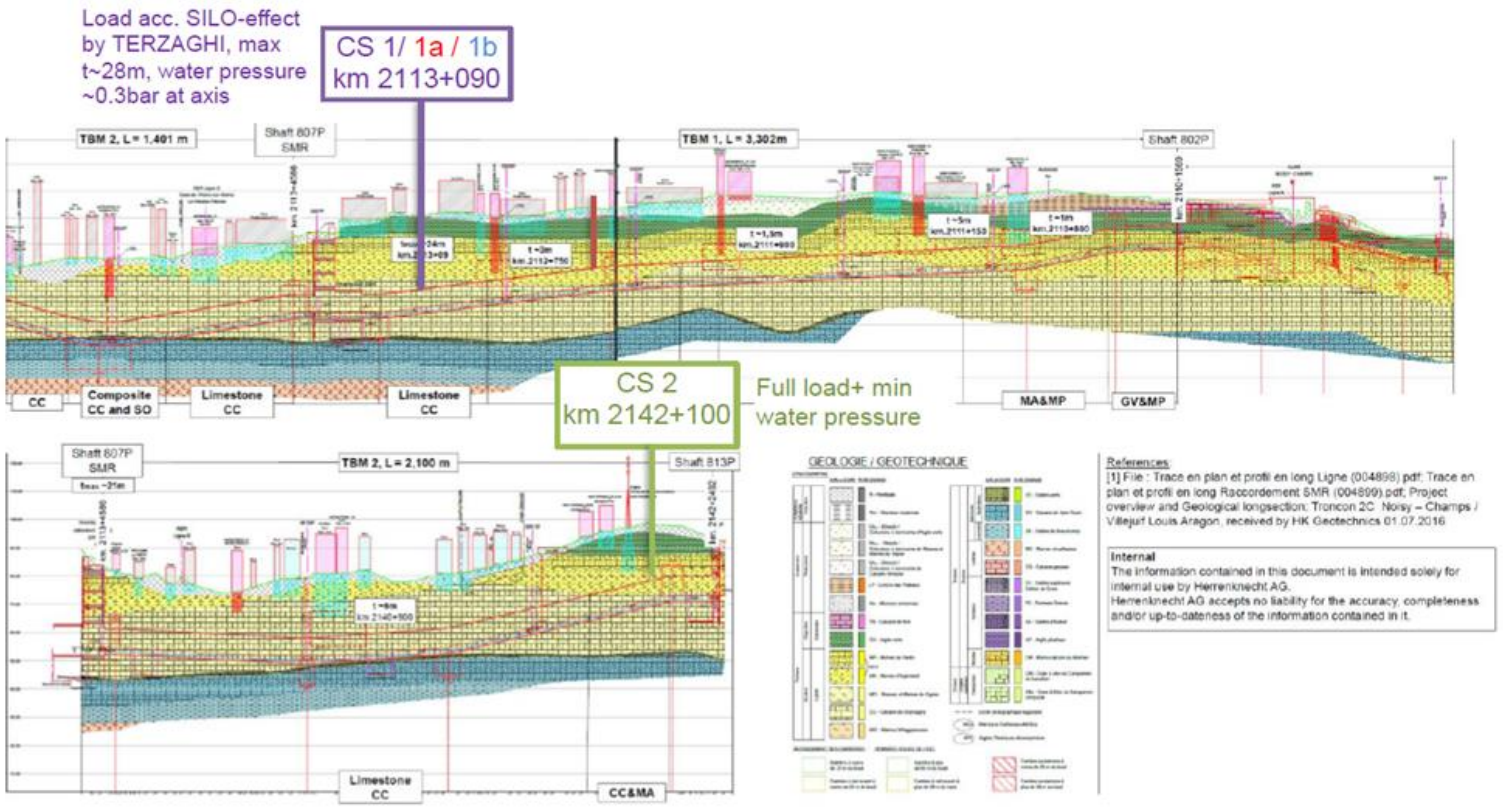
- Anchored EPDM gaskets in conjunction with hydro expansive seals.
- Connectors: M16 type No.2 per segment with bushings in polyamide
- Temporary bolts: Carbon steel size T20 550 mm long
- Guiding rods: L=550 mm; 50 mm diameter





The Geology and the Geotechnical properties

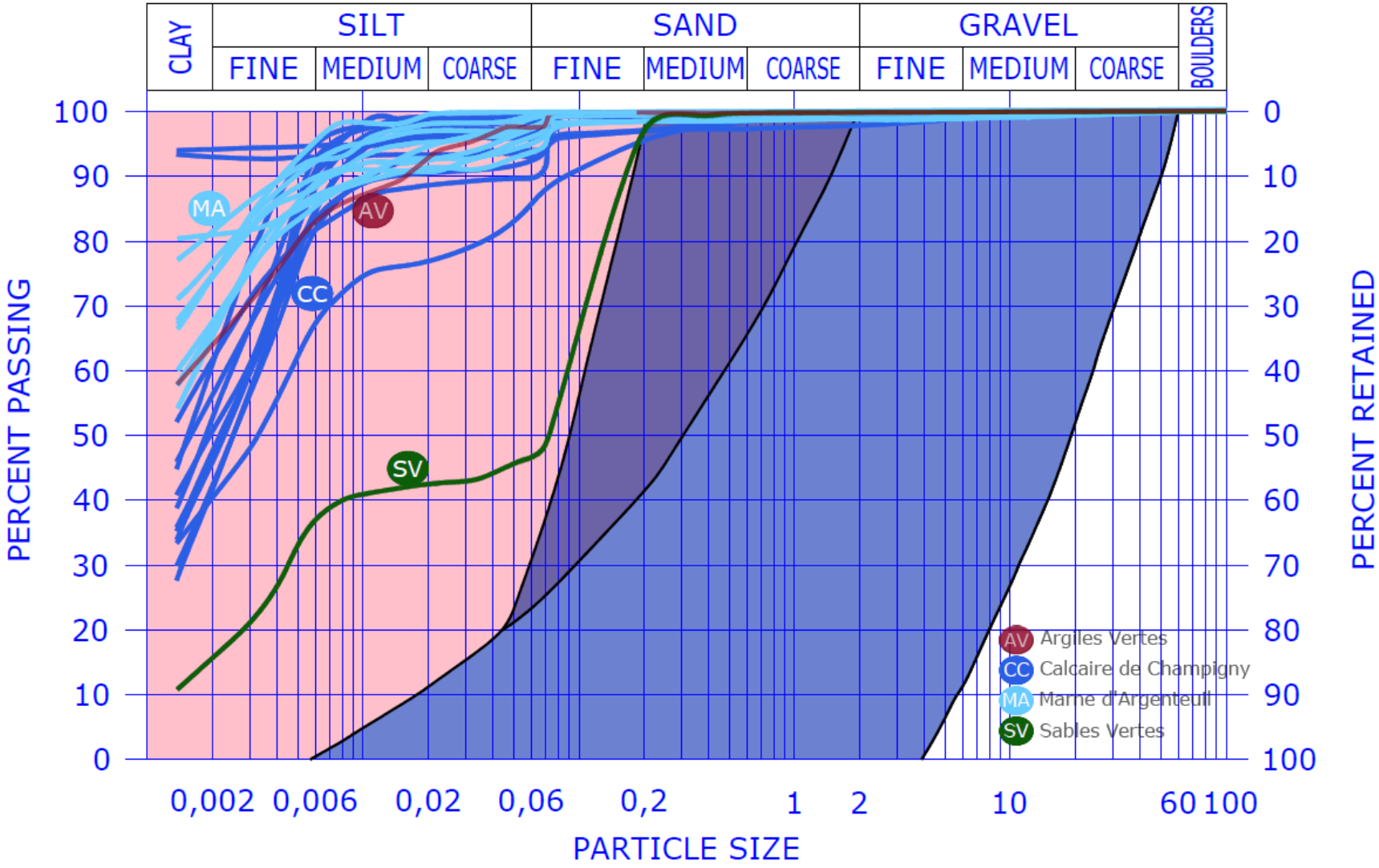
- Approximately 60% of the length of the tunnels are through altered limestones namely *Calcaire de Champigny* (CC) and 40% have to be excavated through clayey soil formations called *Marnes d' Argenteuil* (MA)



References
[1] File : Trace en plan et profil en long Ligne (004898).pdf; Trace en plan et profil en long Raccordement SMR (004899).pdf; Project overview and Geological longsection: Tronçon 2C Noisy – Champs / Villejuif Louis Aragon, received by HK Geotechnics 01.07.2016

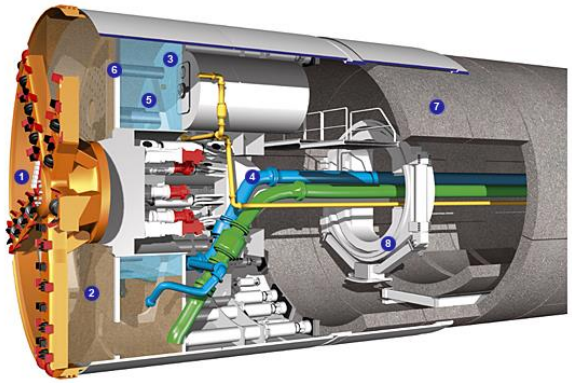
Soil types at tunnel face elevation acc. to [1]	γ [1] [kN/m³]	φ' [1] [°]	c'/cu [1] [kPa]	Rc [2] [MPa]	ETunnel [1] [MPa]	ν [1] [-]	K0 [1] [-]
a) Clay / Argile verte (GV)	19	15	20/80	0,2	24	0.35	0.8
b) Marl / Marnes d' Pantin (MP)	19	25	20/120	-	42	0.35	0.6
c) Marl / Marnes d' Argenteuil (MA)	19	20	15/20/25 80-130	0.15 - 0.20	51/75/ 105	0.35	0.6
d) Limestone / Calcaire de Champigny(CC)	19	30	15-40/ 100-170	-	80/200/ 280/412	0.3	0.5
e) Limestone / Calcaire de Saint Ouen (SO)	17	30	30	-	612	0.3	0.5

Geotechnical properties: Grain size distribution

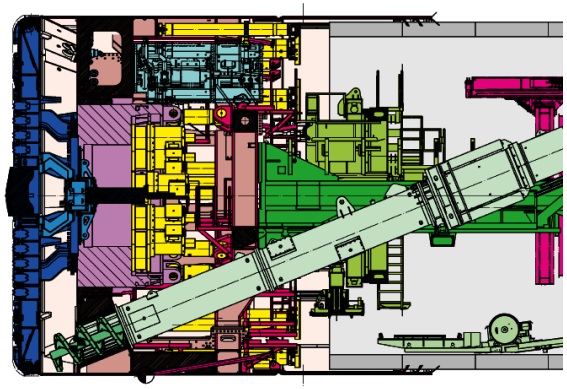


TBM Selection criteria: Slurry Shield or EPB?

In the contest presented the selection involves EPB Type or Slurry Shield Machines
(SM V4 or SM V5 in accordance with DAUB Classification)



(SM V5)



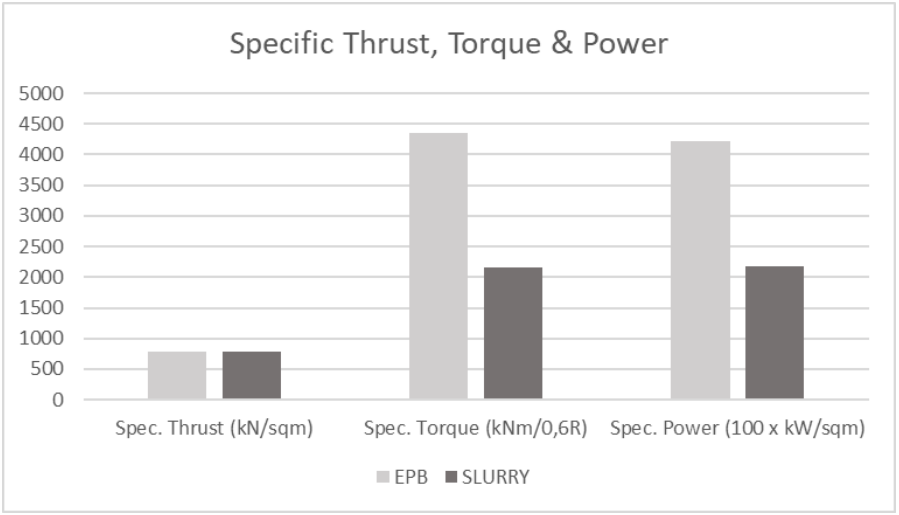
(SM V4)

- When the excavation has to be performed in highly urbanised areas at shallow depth the selection of the machine is crucial for the success of the project.
- Selection should be made in accordance with admissible surface settlement.
- FACE SUPPORT is the key factor when tunnelling in soft ground under water table at shallow depth.
- Settlement depends on capability of developing and controlling Active Pressure on face to counterbalance stress generated by excavation.

TBM Selection criteria: EPB vs SS – Advantages & Disadvantages

- Slurry not adapted for $\mathrm{k} > 5 \times 10^{-3}\ ms^{-1}$
- EPB not adapted for soils with content of fine grained soils (<0,06 mm) >30%; Injection of Fillers (Carbonaceous & Bentonitic) has increased the field of application in granular soils

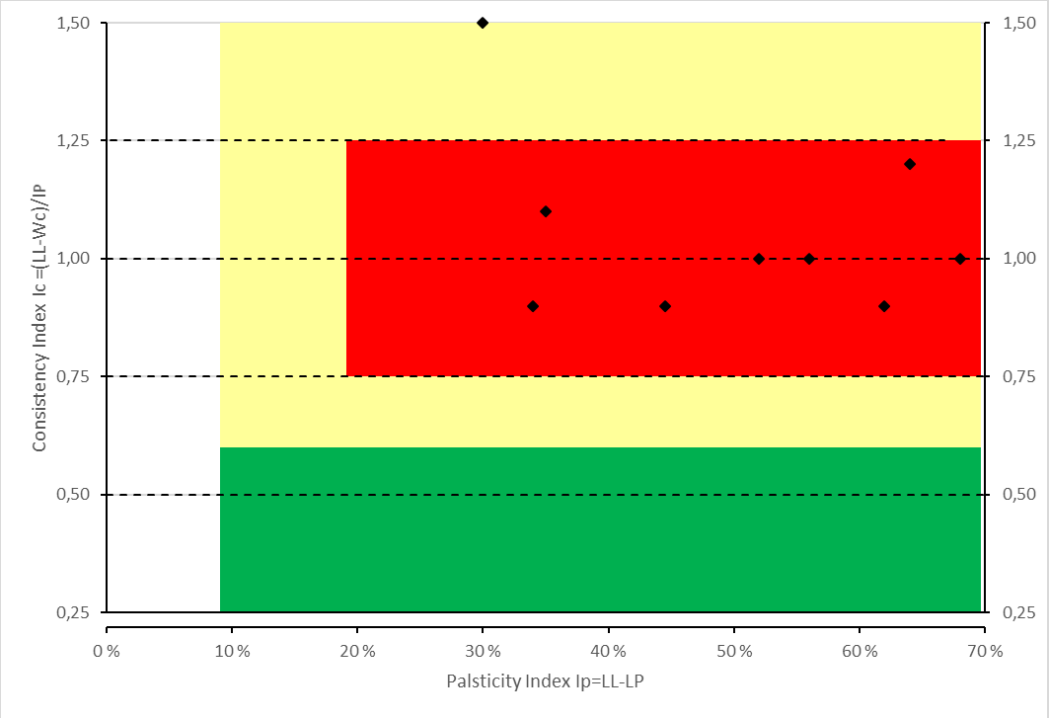
	EPB	Slurry Shield
Water pore pressure	Could represent a limit	Higher pressure can be achieved
Torque required	Higher than SS	Lowest values
Confinement pressure	Linear distribution	Omogeneous pressure
Tunnel diameter	Screw conveyor may limit the nominal exc.diameter	$D_{SS} \gg D_{EPB}$
Separation Plant	Not required	Could represent a major difficulty in urban areas
Contractor experience	Learning period depend upon personnel availability	May requires prolonged learning time



The Grand Paris Metro Line 15 – Potential Risks

TBM SELECTION IS RATHER COMPLEX AND CRITICAL => MULTI CRITERIA ANALYSIS SHOULD BE ALWAYS IMPLEMENTED!

- Potential risks identified:
  - Cavities and obstacles along the tunnel route
  - Boulders or unaltered rock formations along the alignment
  - Clogging
  - Cohesionless sands



The Grand Paris Metro L15 T2C - Multi-Criteria Matrix

Criteria	Parameters	EPB		Slurry Shield		Line 15 Conditions	EPB	Slurry Shield
		Favorable	Unfavorable	Favorable	Unfavorable			
Geology	Grain Size	< 0,06mm (>25%) < 0,002mm (>5%)	> 2mm (10%)	> 2mm (10%)	< 0,06mm (>25%) < 0,002mm (>5%)	< 0,06mm (>25%) < 0,002mm (>5%)	Very Favorable	Sligthly Favorable
	Permeability	<= 10^{-6} - 10^{-7} m/s	>= 10^{-3} m/s	>= 10^{-3} m/s	<= 10^{-6} - 10^{-7} m/s	>10^{-7} m/s	Favorable	Unfavorable
	Abrasiveness	Foam injection may have a positive affect of the tools wear		Bentonite slurry have great influence on friction reduction		Low abrasiveness	Favorable	Very Favorable
Gelogical Risks	Cavities	For both types of machines the cavities represent a difficlut condition				The possibility of encounter cavities cannot be excluded	Adoptable with precautions	Adoptable with precautions
	Swelling	Limited by the reduced quantity of water inside the chamber			Elevated risk due to use of water for slurry	Negligible risk	Very Favorable	Sligthly Favorable
	Clogging	Machine to be equipped with facilities to inject anti clogging additives inside the chamber			For high percentage of fines particles the separation from muck could represent a practical limit	Unwanted risk: Atterberg Limtis shows high risk of clogging	Very Favorable	Unfavorable
Operational Risks	Control of the consinement pressure	Not rapidly governed		Pressure can be controlled in extremely rapid manner		Low face-support pressure; Negligible risk	Favorable	Very Favorable
	Control of the volume loss	Quantity of excavated material can be monitored precisely			Excavated volume cannot be monitored from the machine	Unwanted risk	Very Favorable	Unfavorable
	Management of the muck		Prolonged time for classification	Muck not polluted by additives after separation of the bentonite	In case of fine grained soils separation of the bentonite is not practicable	Silty Clayey soils	Very Favorable	Unfavorable

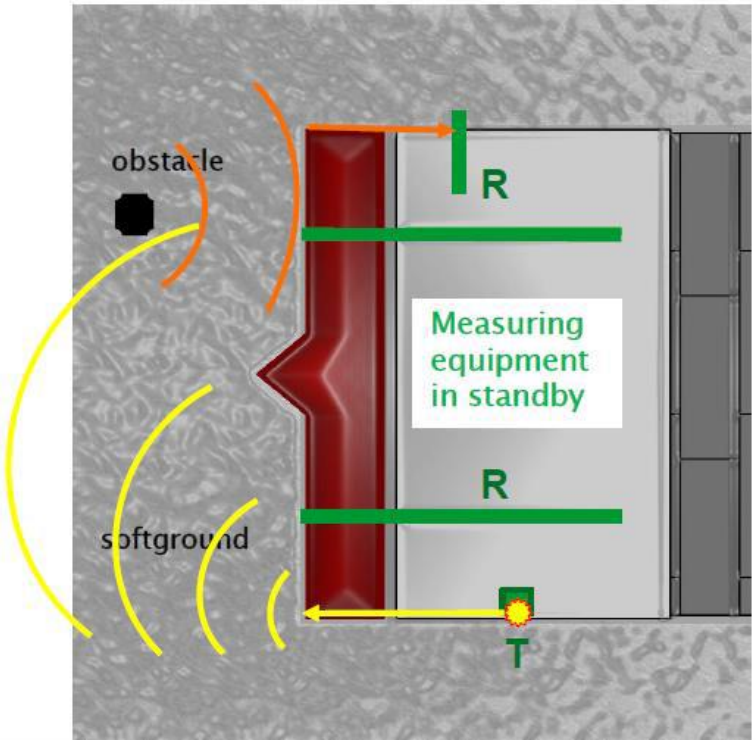
The Grand Paris Metro L15 T2C - The selected machines

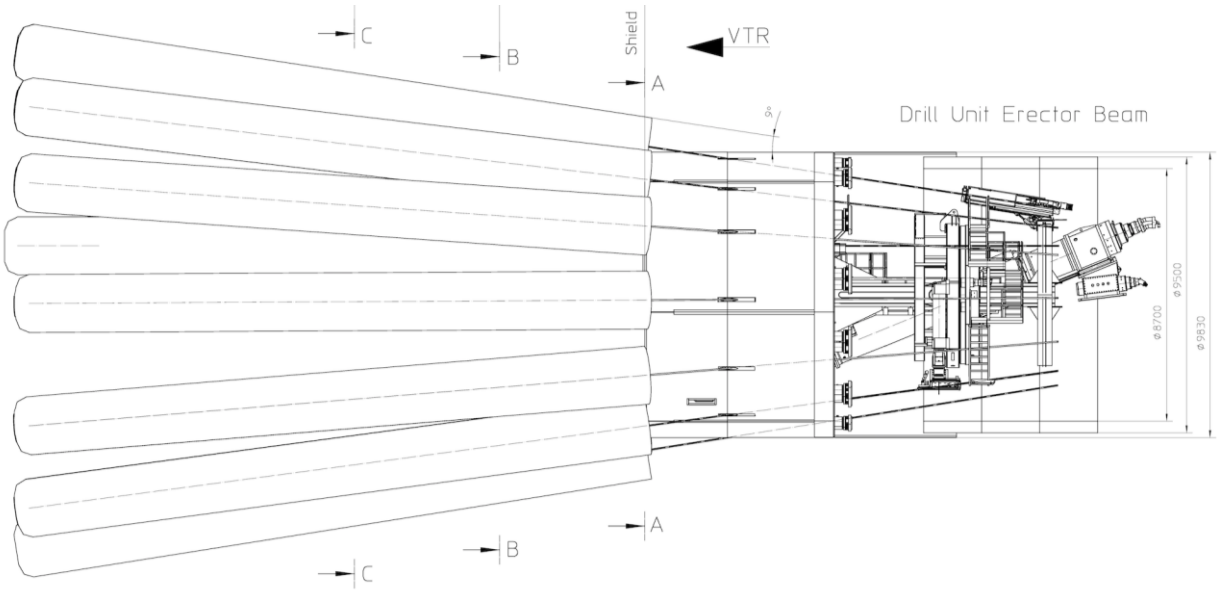
- Machine Type: Earth Pressure Balanced
- Manufacturer: Herrenknecht

- Nominal Excavation diameter: 9.860 mm
- Total Length and Weight: 106 metres; 1.600 t
- Cutterhead Power: 11 x 350 kW = 385 MW
- Tools: 46 cutters size 17" + 168 scrapers
- Opening ratio: 37% - 40% central section
- Main Bearing diameter: 5.000 mm
- Nominal Torque: 17.988 kNm
- Breakout Torque: 24.103 kNm
- Maximum Thrust: 56.032 kN

Paris L15 T2C - The selected machines

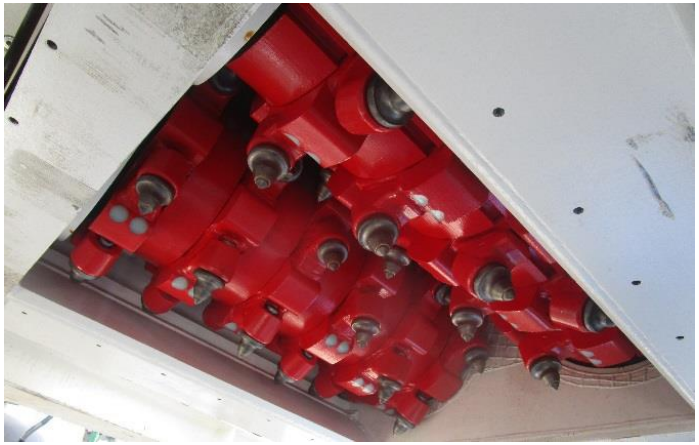
- Dealing with risk of cavities: **S**onic **S**oftground **P**robing **E**PB: **SSP-E**
- Minimizing the Risk by means of SSP-E, Probing Ahead and Machine parameters monitoring in conjunction with probing ahead

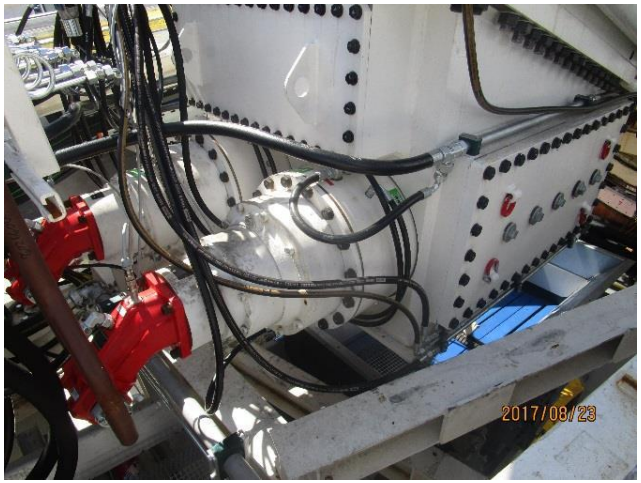




Paris L15 T2C - The selected machines

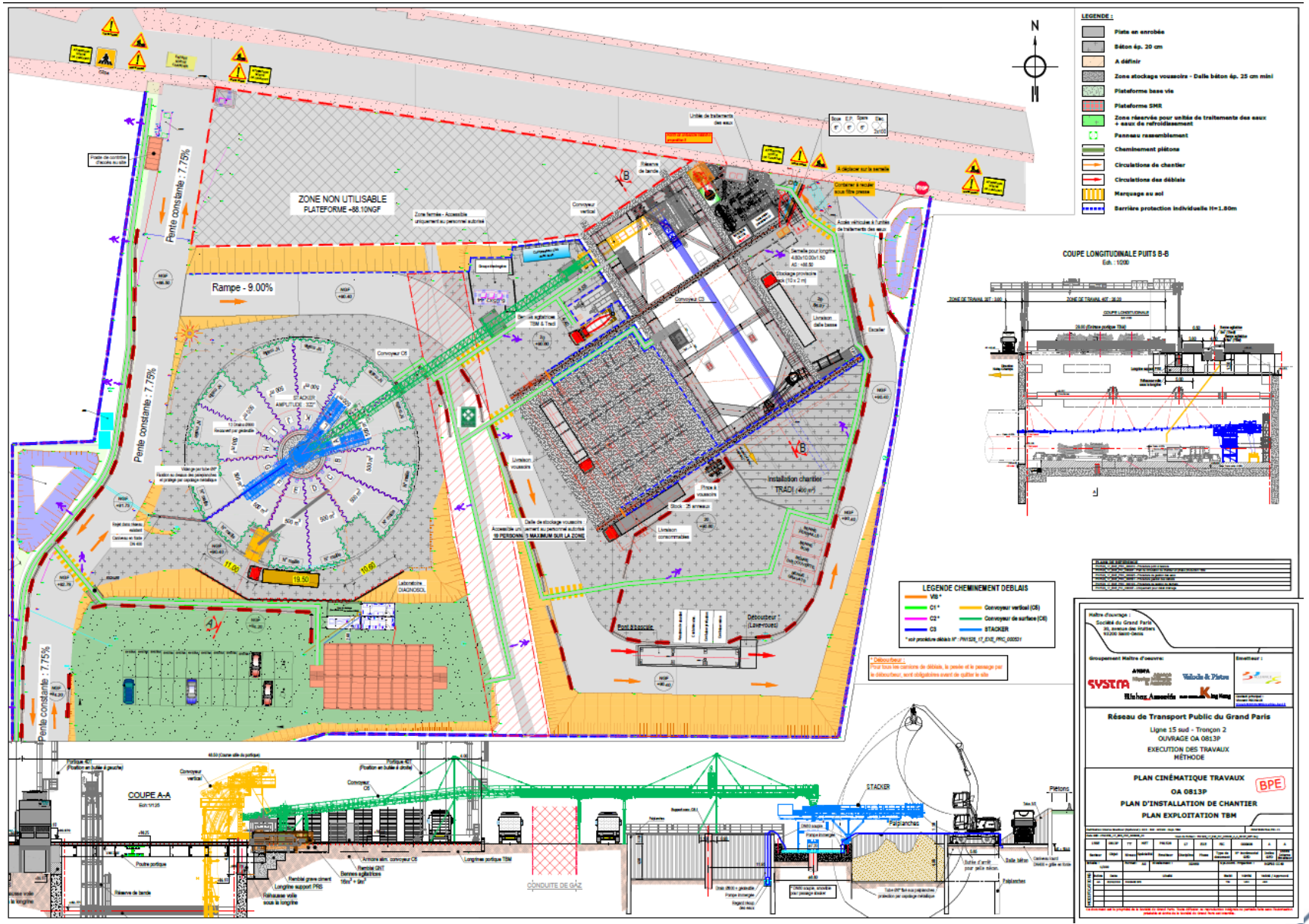
- Screw Conveyor size & Power: 1.000 mm; 630 kW
- Maximum Boulders size: 400 mm
- Stone Crusher designed to suit the space availability





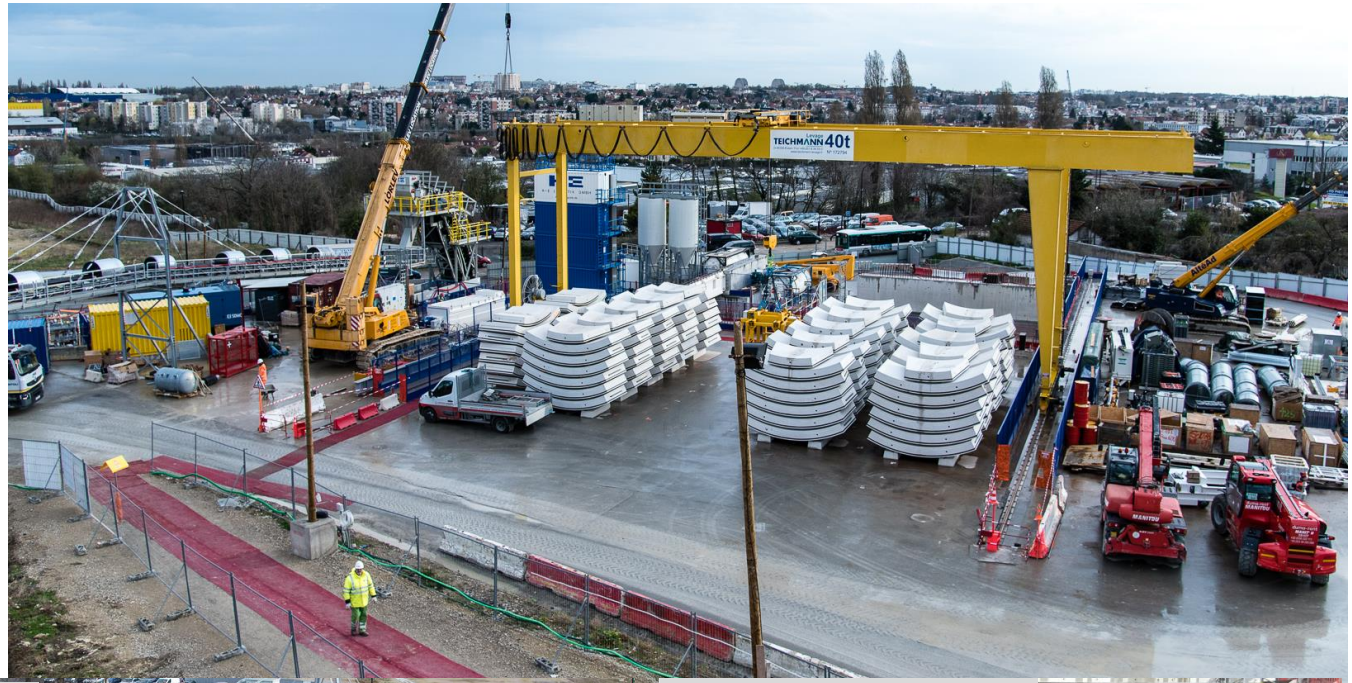
Paris L15 T2C - The lesson learned

- The Auxiliary Equipment selection and site layout optimization

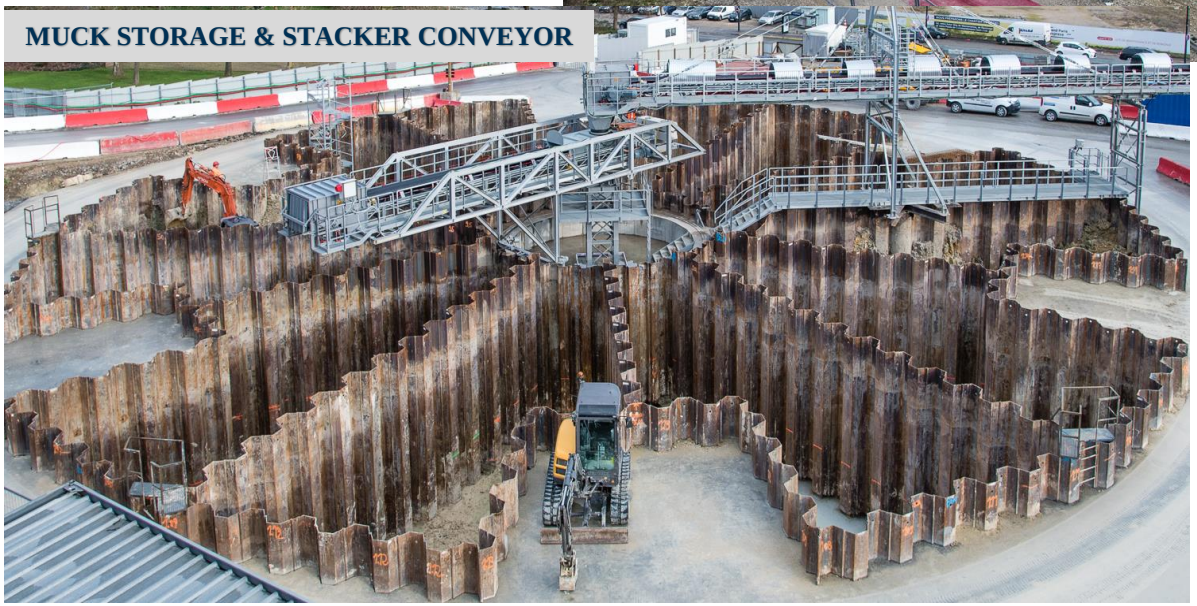


Paris L15 T2C - The lesson learned

- The Auxiliary Equipment selection and site layout optimization.
- Confined area requires detailed design for logistics.
- Cycle time may be influenced by availability of muck disposal area.

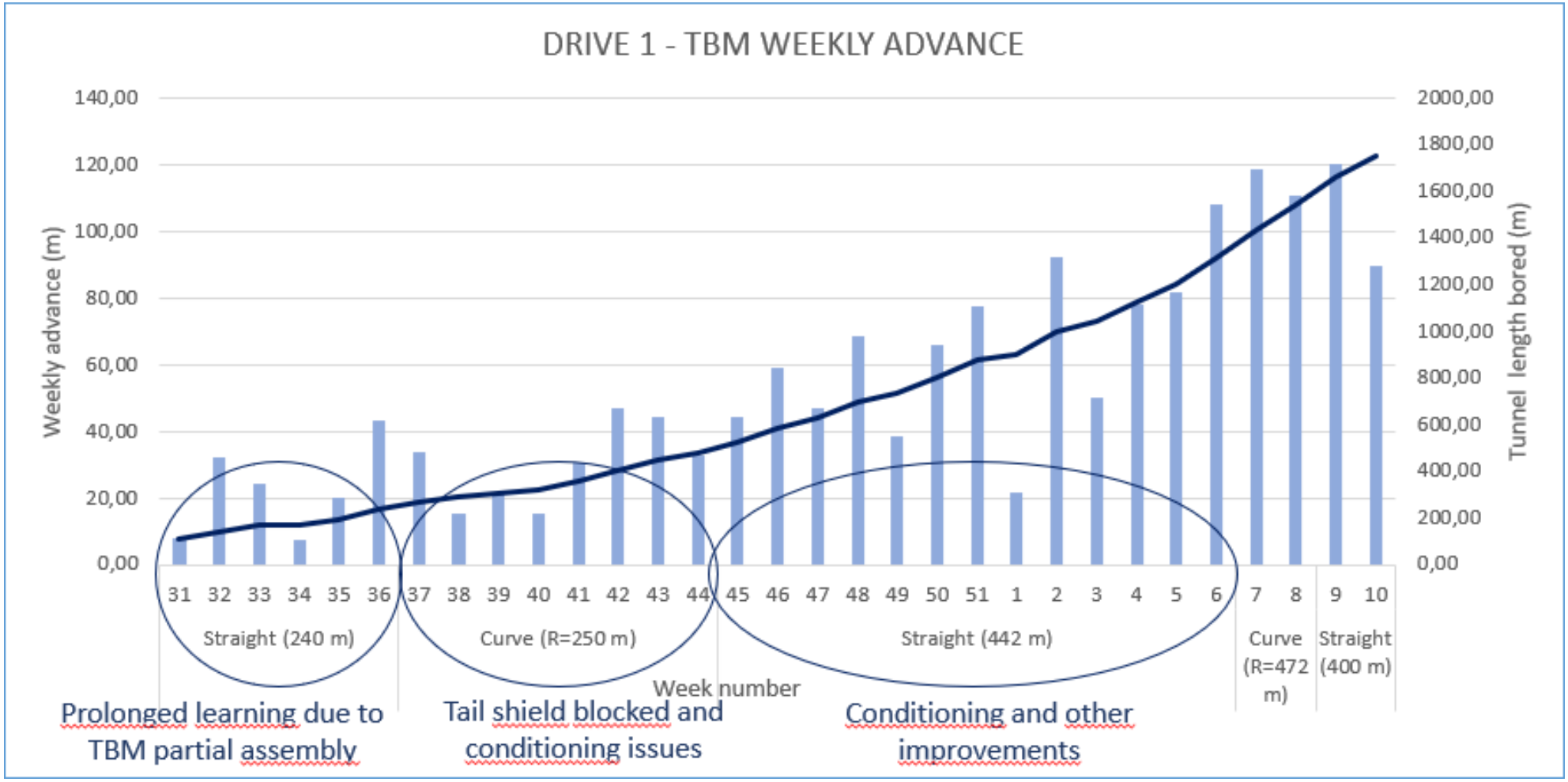


MUCK STORAGE & STACKER CONVEYOR



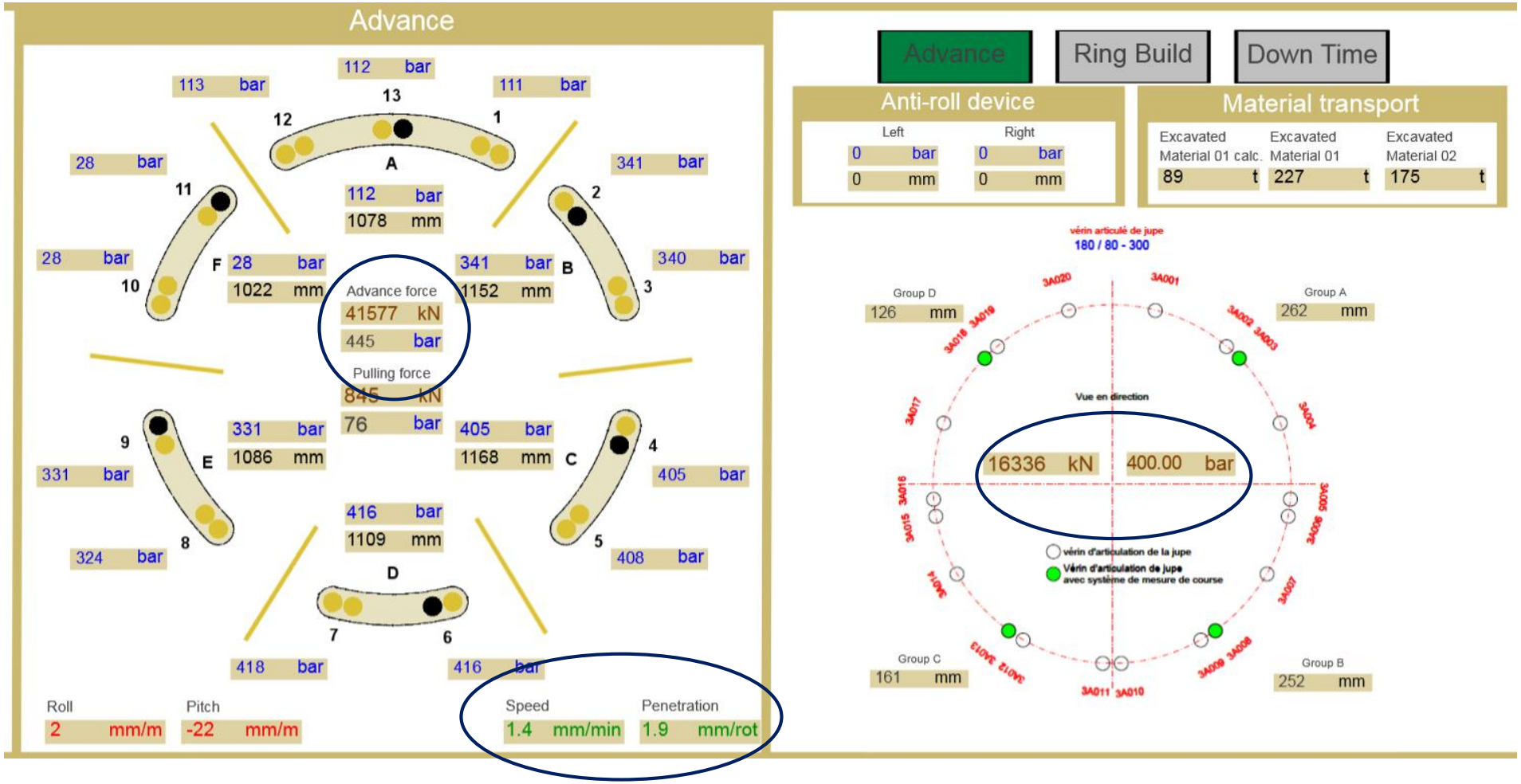
THE LAUNCHING SHAFT

Paris L15 T2C - The lesson learned



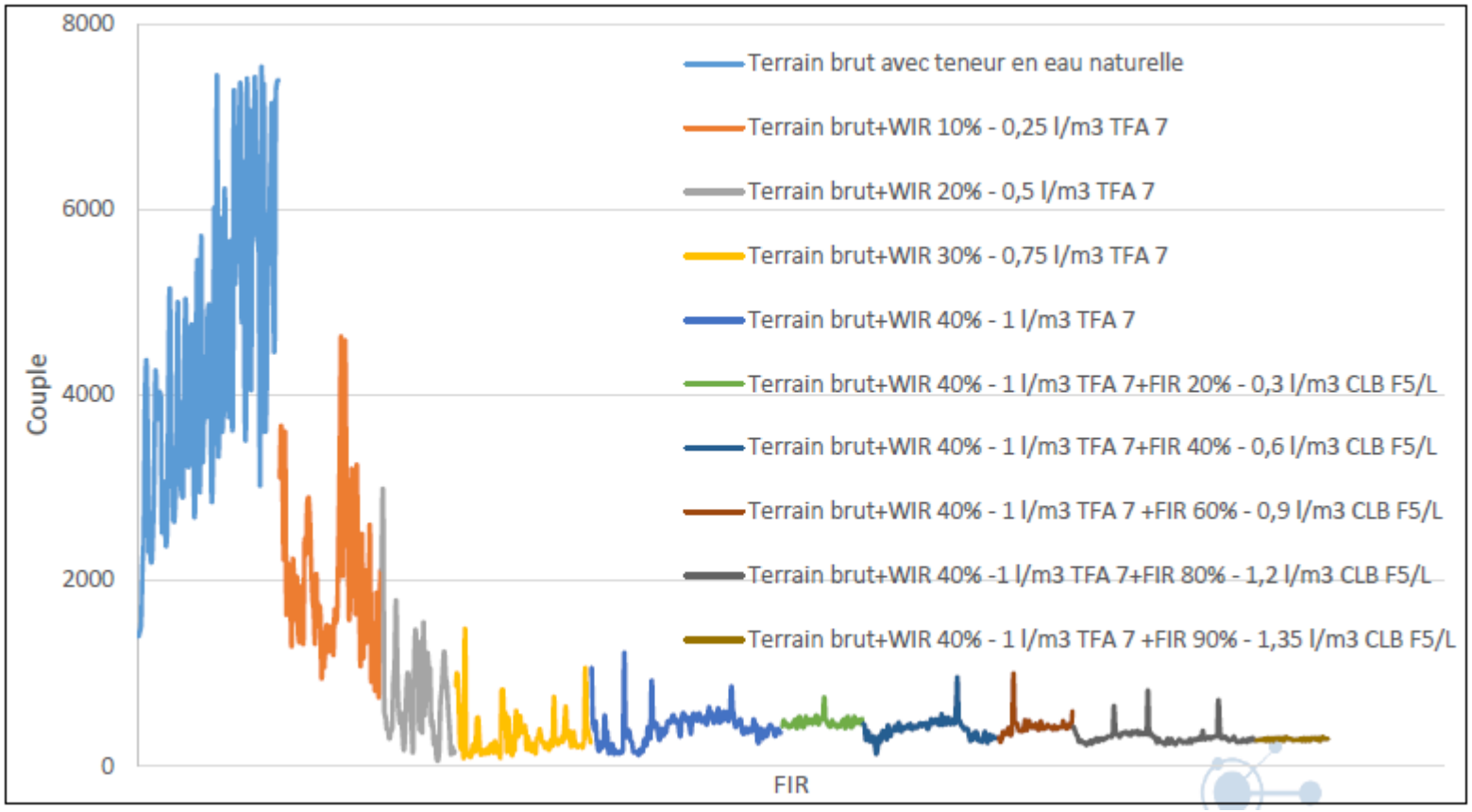
Paris L15 T2C - The lesson learned

- Difficult advance in 250 m radius curve resulting in Tail Shield Blocked



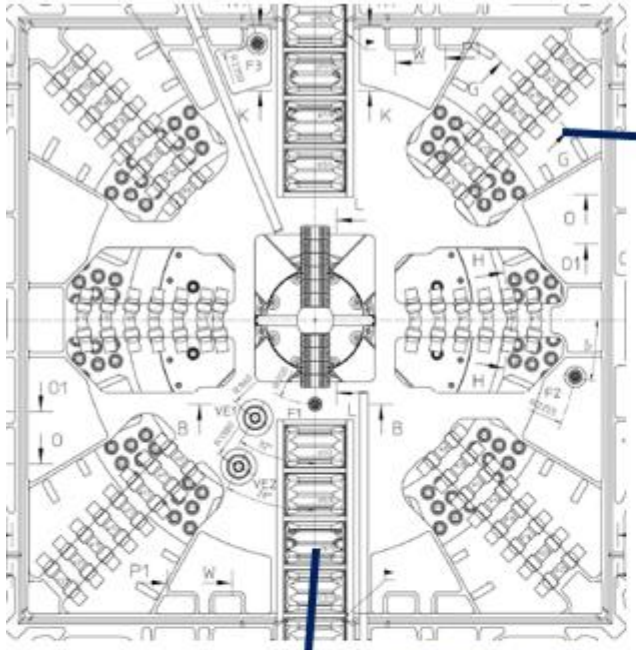
Paris L15 T2C - The lesson learned

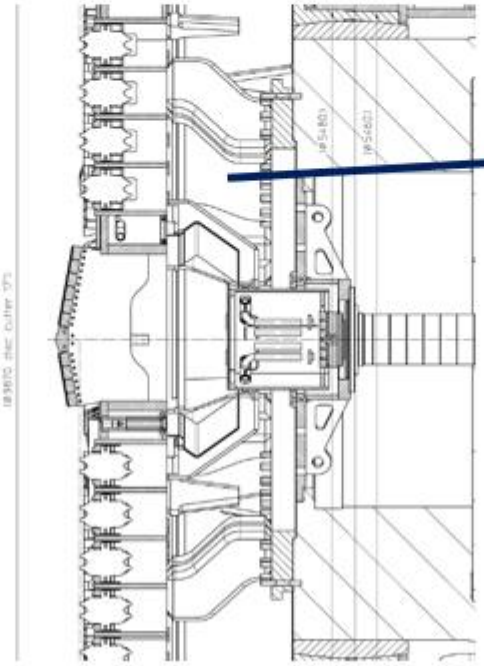
- The conditioning issue: tests performed in laboratory shows good results in terms of slumps and torque reduction tests.
- WIR (%) Not compatible with vertical conveyor!
- Clogging experienced on the cutterhead!



Paris L15 T2C - The lesson learned

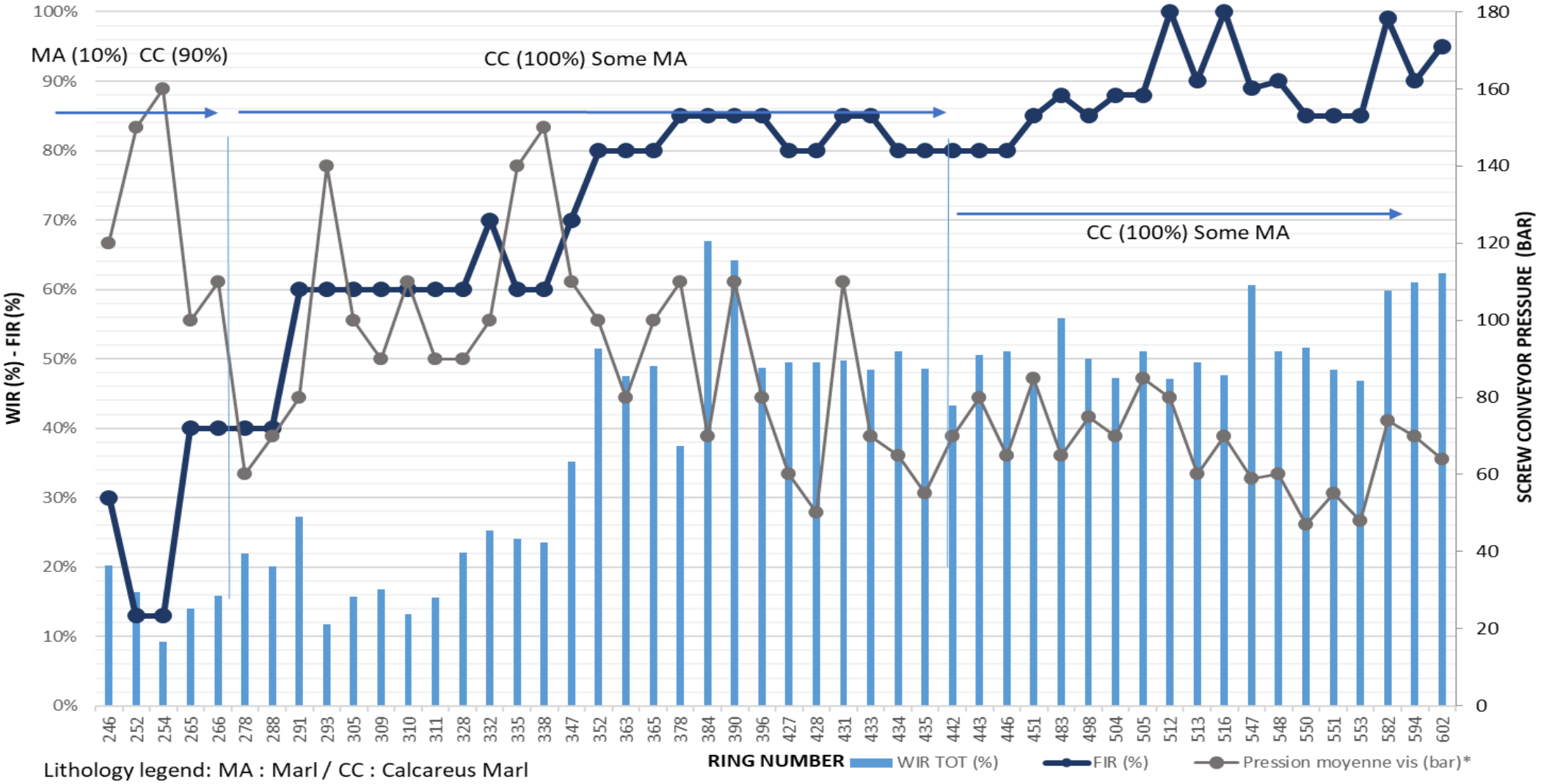
- Clogged cutterhead: centre zone and buckets





Paris L15 T2C - The lesson learned

- The conditioning issue: optimization of parameters during the drive



Conclusions

- Selecting the type of machine for excavation at shallow depth in highly urbanised areas requires a deep analysis of the Risks.
- Geotechnical data are fundamental for the correct risks evaluation.
- The multi-criteria approach adopted for the Section C alignment of Paris Line 15 has been proved successful.
- When EPB is selected the implementation of an accurate analysis of the conditioning agents behavior shall be performed to prevent or minimize the risk of clogging.
- The selected machine should be equipped to cope with critical conditions.
- Accurate selection of the auxiliary equipment optimize the efficiency of the production cycle as well as the detailed design of the working site areas.
- Availability of experienced personnel minimize the learning phase.