



Milano Metro 4

Urban excavation with EPB in sandy gravelly soils

Eng. Davide Fraccaroli (Metro Blu S.c.r.l.)

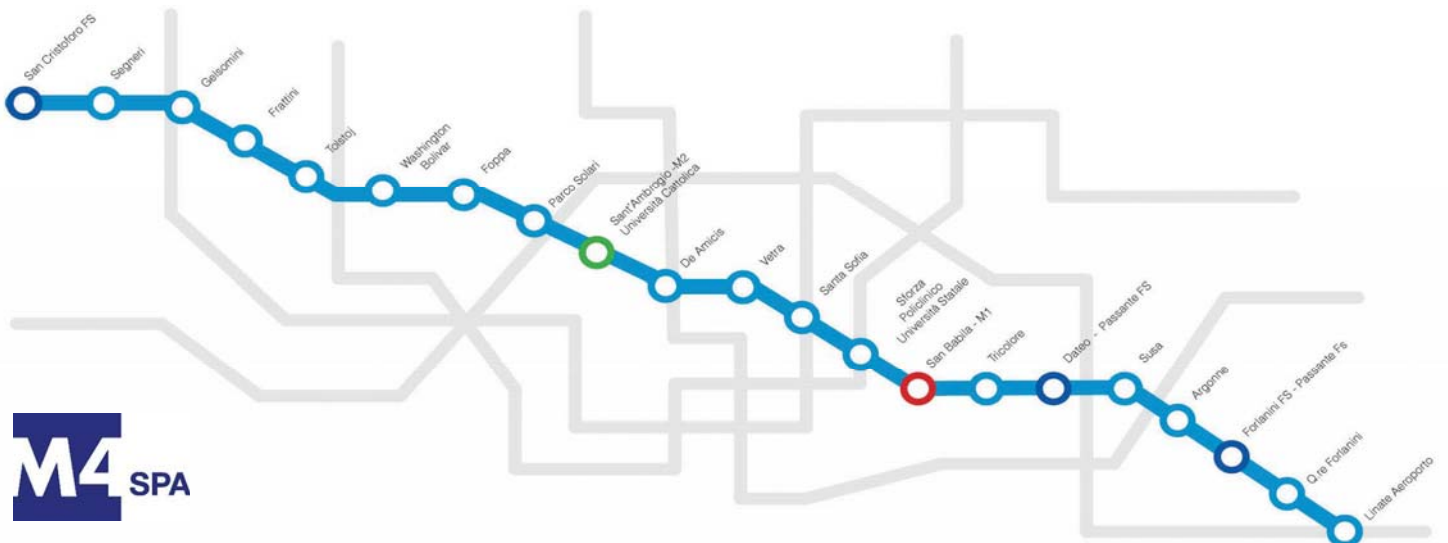
Eng. Filippo Cignitti (M4 S.p.A.)

Kolloquium

Maschinelle Vortriebe

ETH Zürich, Donnerstag, 19.05.16

INTRODUCTION



Commitment Informations

CONTRACTING AUTHORITY / WORKING PLACE: Municipality of Milan / Milan

KIND OF COMMITMENT: Building permit and management of the new Milan Metroline 4, from San Cristoforo Station to Linate Airport Station.

TECHNICAL INTERVENTION: Minimetro ATC (Automatic Trains Control) System, based on driverless CBTC (Communication Based Train Control) technology, that will provide a complete set of functions (ATP, ATO, ATS).

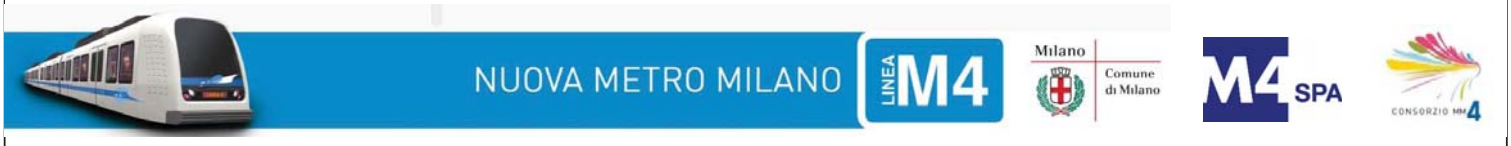
COMMITMENT OBJECT: Planning and building infrastructural works, systems and supplies (Trains included). Partial financing of structural interventions. Metroline maintenance, ordinary and extraordinary management, administrative and financial management.

COMMITMENT TIME: 370 months

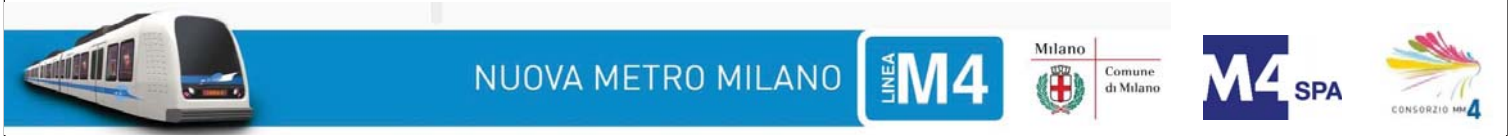
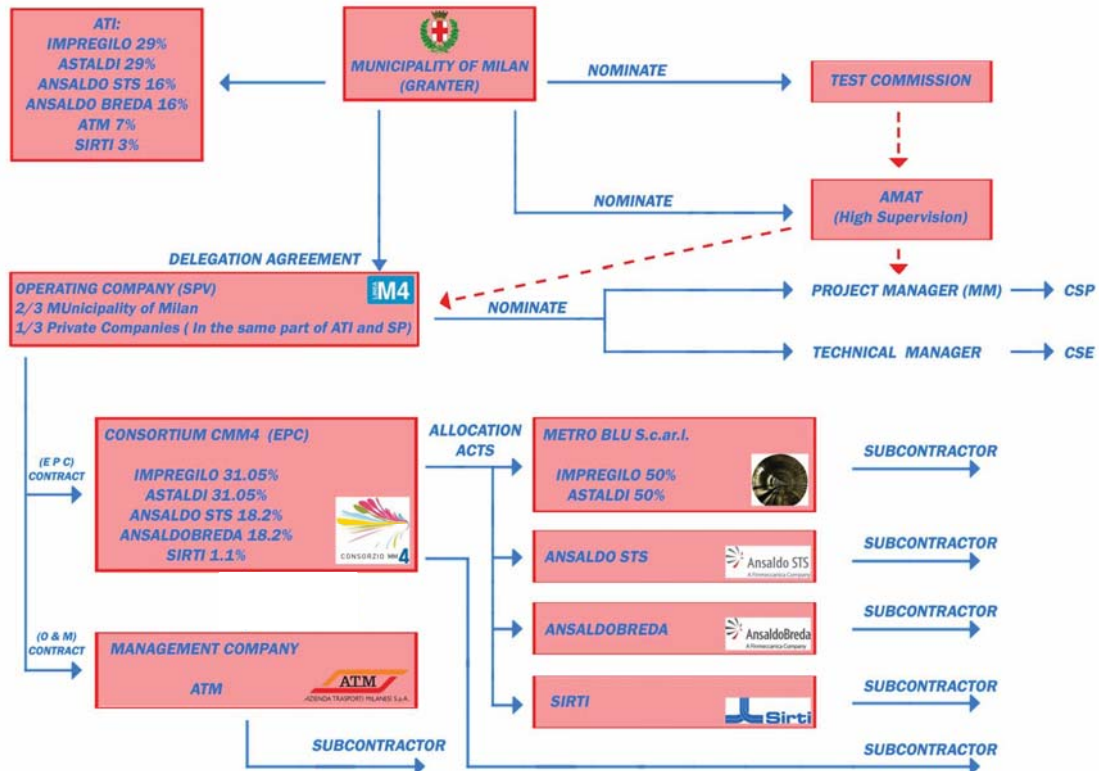
- **BUILDING TIME:** 88 months
- **OPERATION TIME:** 282 months

PROJECT VALUE: 1.682 M€ (excluding taxes)

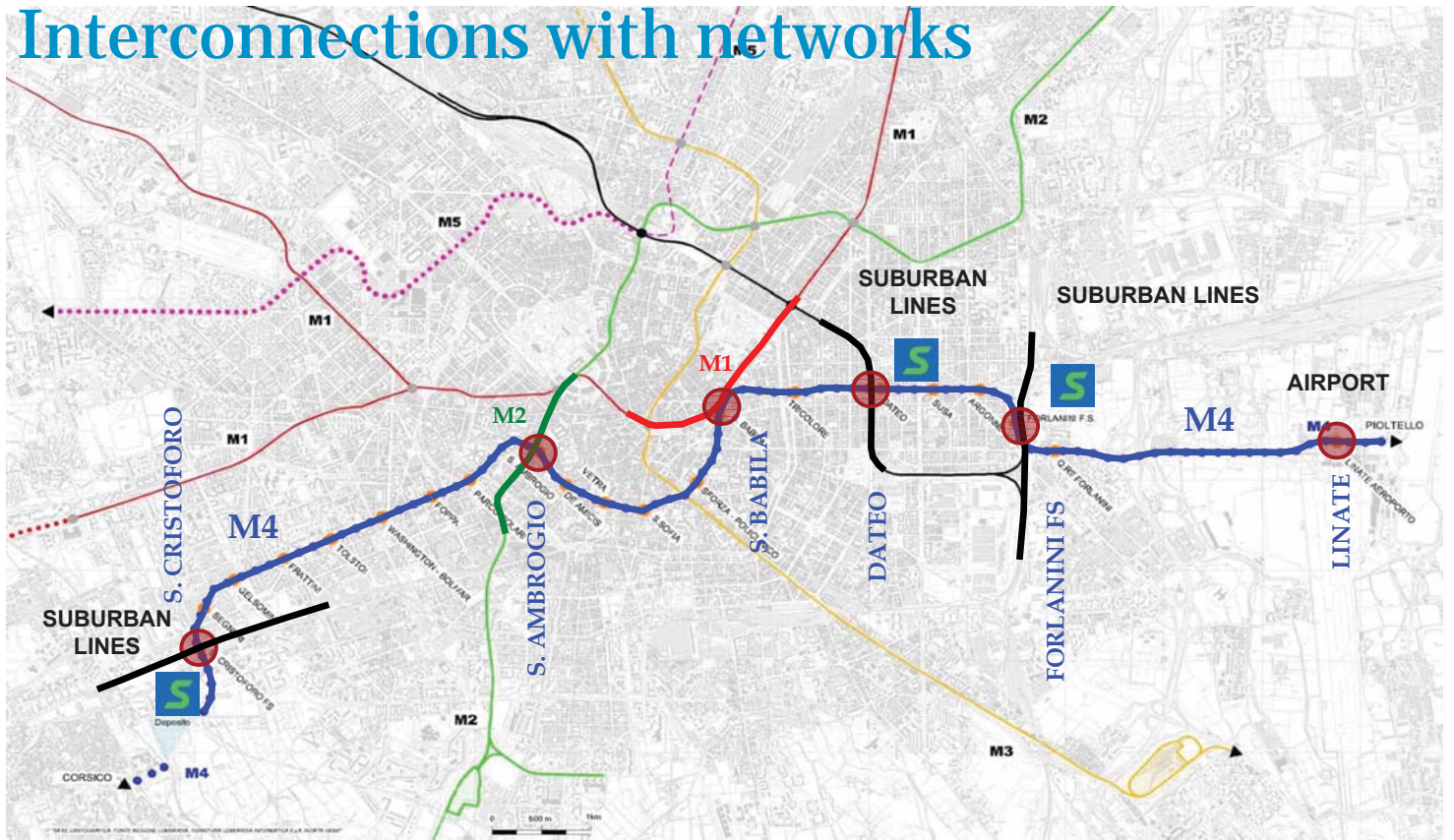
On **SEPTEMBER 2013** the **CIPE** approved the Metroline 4 Project, with technical limitations.



Contractual Structure



Interconnections with networks

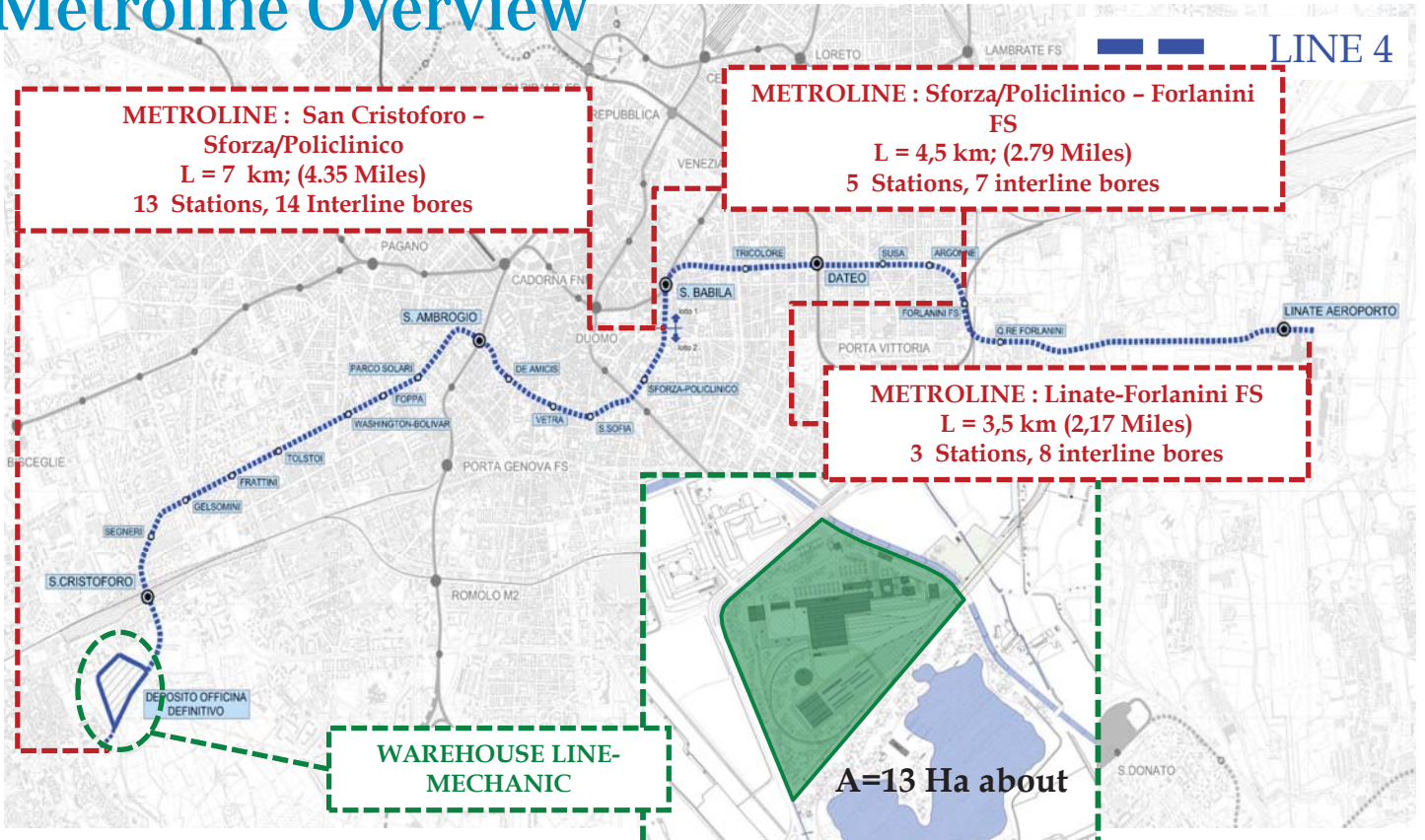


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LINEA M4



Metroline Overview



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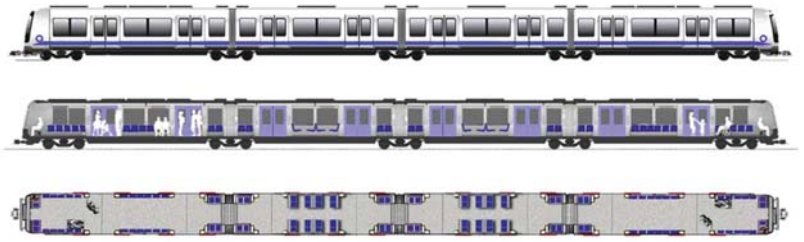
LINEA M4



Technical Features

General Features:

- Metroline Extension: 15 km about (9,32 Miles)
- Stations: 21;
- Interlines Bores: 29;
- Line-Mechanic Warehouse: 1 (San Cristoforo);
- Vehicles: 47 (40+7 provisions) trains each composed by 4 cars with articulated configuration, able to operate in either direction;
- Railroad Equipment: Model Massive Milano in the central line, Milan Modified in the external lines;
- Line tunnels: Two tunnels with an individual track in the external lines, about 6,50 m large, two tunnels with an individual track in the central line, about 9,15 m large.
- Contact Line: On the 3° line.



Rolling Stock Features:

- Regular Headway: 90 s;
- Minimum Headway: 75 s;
- Maximum Capacity: 24.000 pphpd;
- Maximum Speed: 80 km/h;
- Commercial Speed: ≥ 30 km/h.



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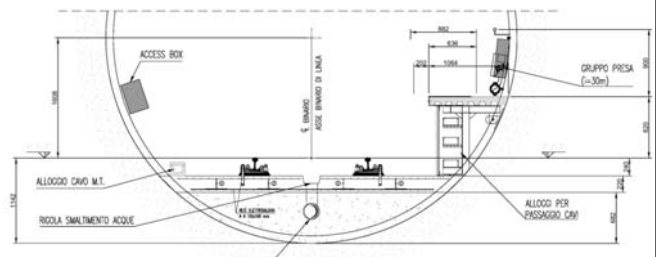
LINEA M4



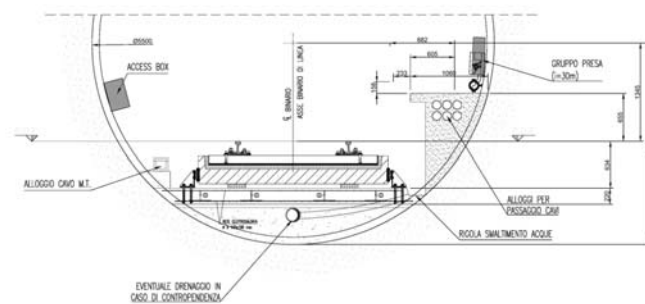
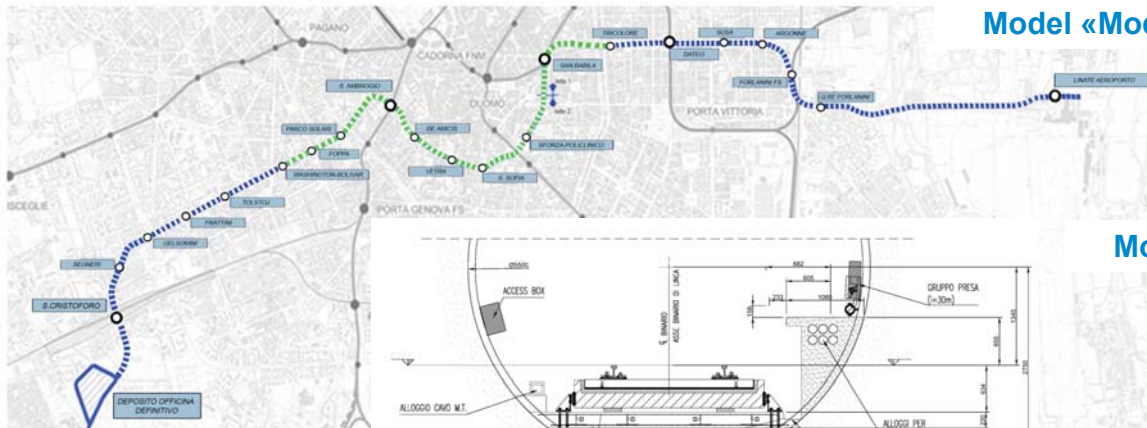
Technical Features – Railroad Equipment

LINE "MASSIVE MILANO"

LINE "MODIFIED MILANO"



Model «Modified Milano»



Model «Massive Milano»

Technical Features :

- Rail without ballast
- Armed concrete base
- Low noise effect
- Low vibration

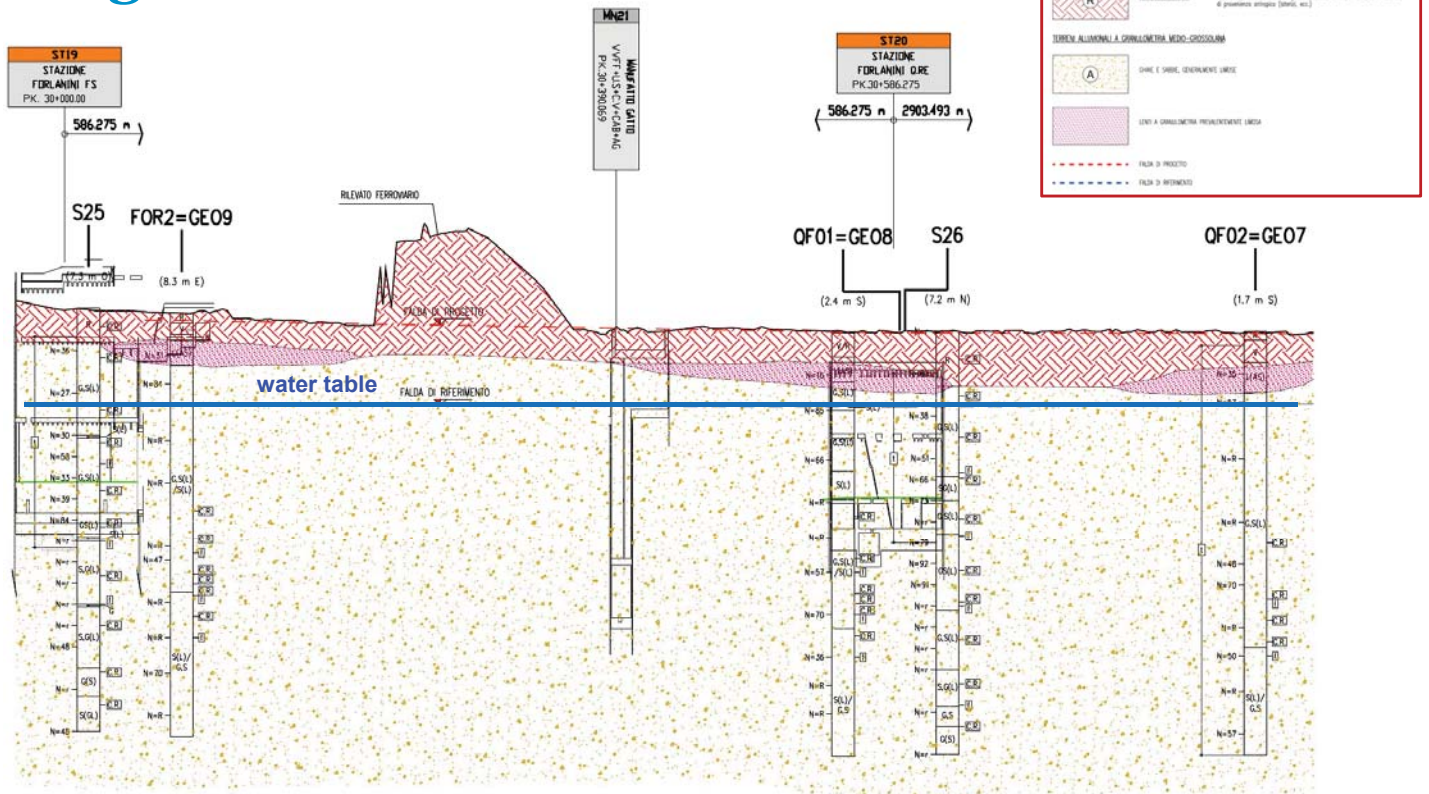


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Longitudinal Profile



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Geotechnical Features

SONDAGGI E NUMERO RELATIVO

PROVE IN FORO:

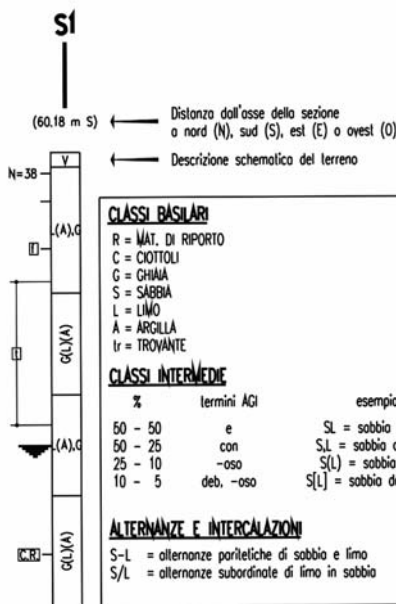
Prove SPT: valori di Nsp1 espressi in colpi/30cm o, in caso di rifiuto, con lo sigla R

Prove di permeabilità: profondità e tipo di prova (I=Lefranc)

FALDA:

Livello stabilizzato di falda rilevato nel piezometro a tubo aperto (I). Indicazione tratto finestrato

CAMPIONE RIMANEGLIATO

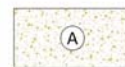


TERRENI SUPERFICIALI



TERRENO DI RIPORTO: Costituito prevalentemente da ghiaia e sabbia talvolta limose, con materiale di provenienza antropica (lateriti, ecc.)

TERRENI ALLUVIONALI A GRANULOMETRIA MEDIO-GROSSOLANA



GHIAIE E SABBIE, GENERALMENTE LIMOSE



LENTI A GRANULOMETRIA PREVALENTEMENTE LIMOSA

FALDA DI PROGETTO

FALDA DI RIFERIMENTO

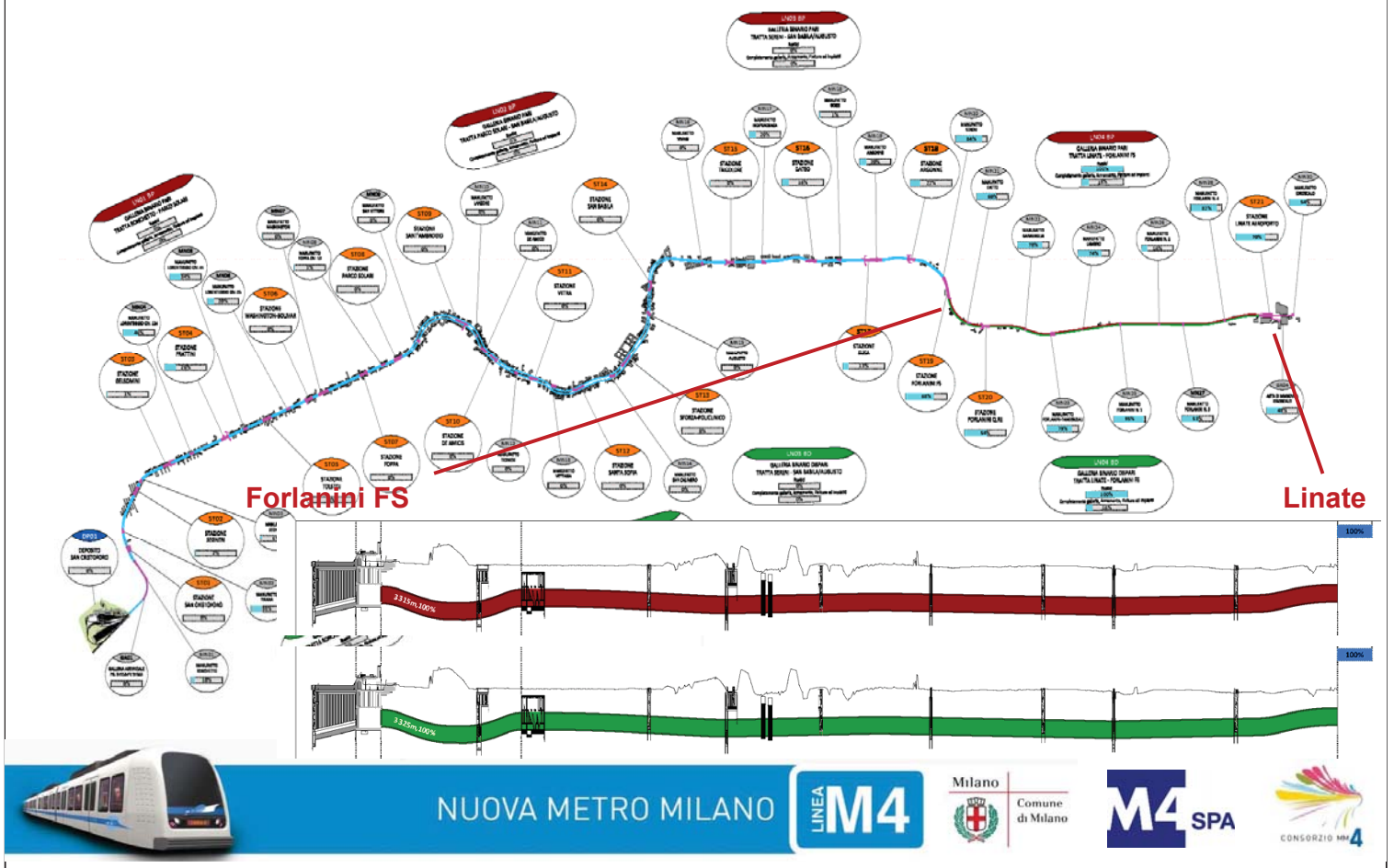
CARATTERISTICHE GEOTECNICHE	UNITA' R - TERRENO DI RIPORTO	UNITA' A - FACIES GHIAIOSA SABBIOSA
FORMAZIONE GEOLOGICA	Attuale	Fluvio-glaciale Murm
LITOLOGIA	sabbia limosa con inclusi laterici	Ghiaia e Sabbia limosa
PESO DI VOLUME γ (N/m ³)	17.5-18.5	20.5-21.5
ANGOLO DI ATRIBITO α (°)	28-32	35
COESIONE c' (kPa)	0.0	0.0
MODULO ELASTICO E (MPa)	20-40	30-360
COEFFICIENTE DI POISSON ν	0.3	0.3



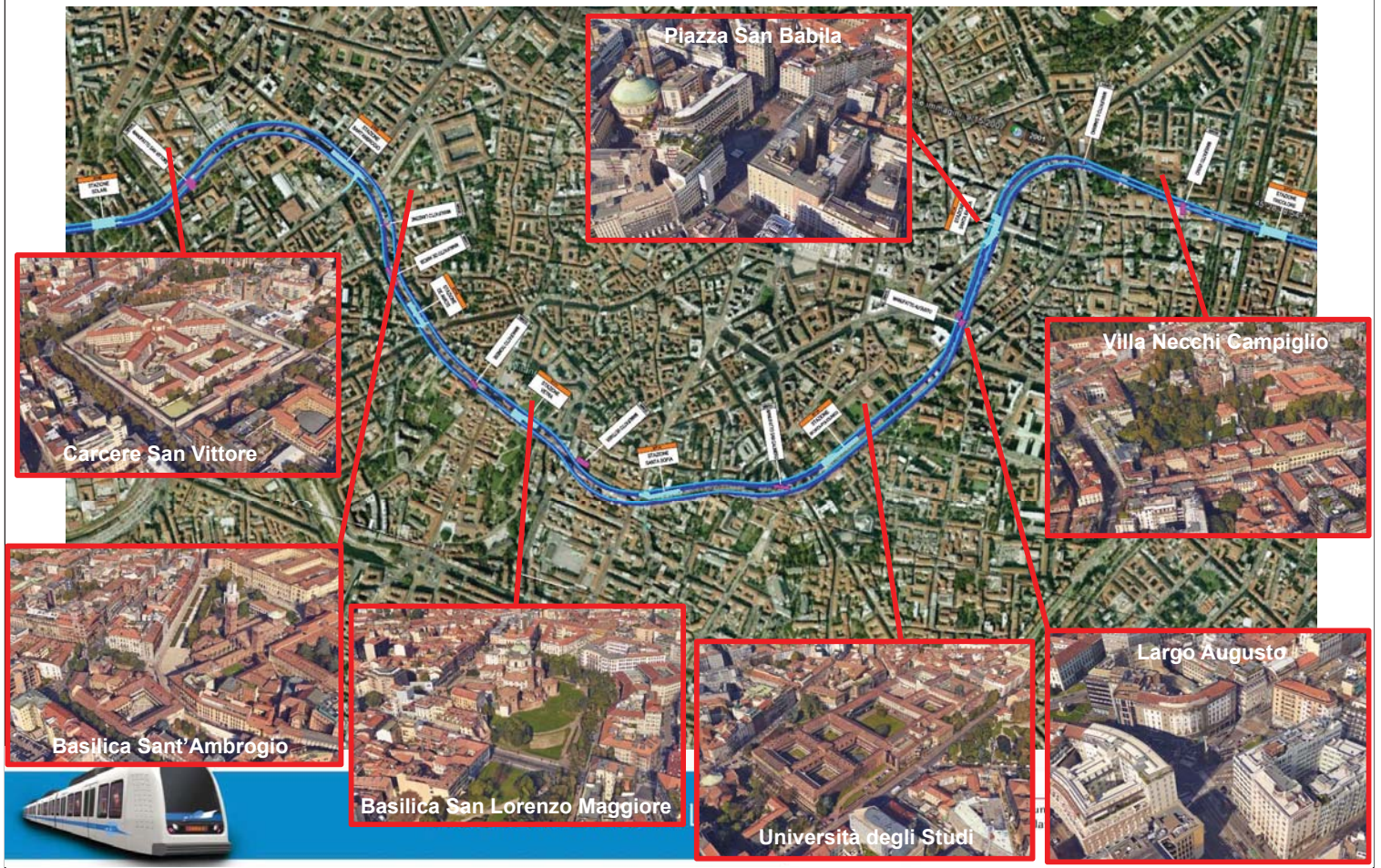
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Timetable – Work Progress



Central Section of Metro Line



CIVIL WORKS AND OPTIMIZATIONS OF MECHANIZED TUNNELS PROJECT



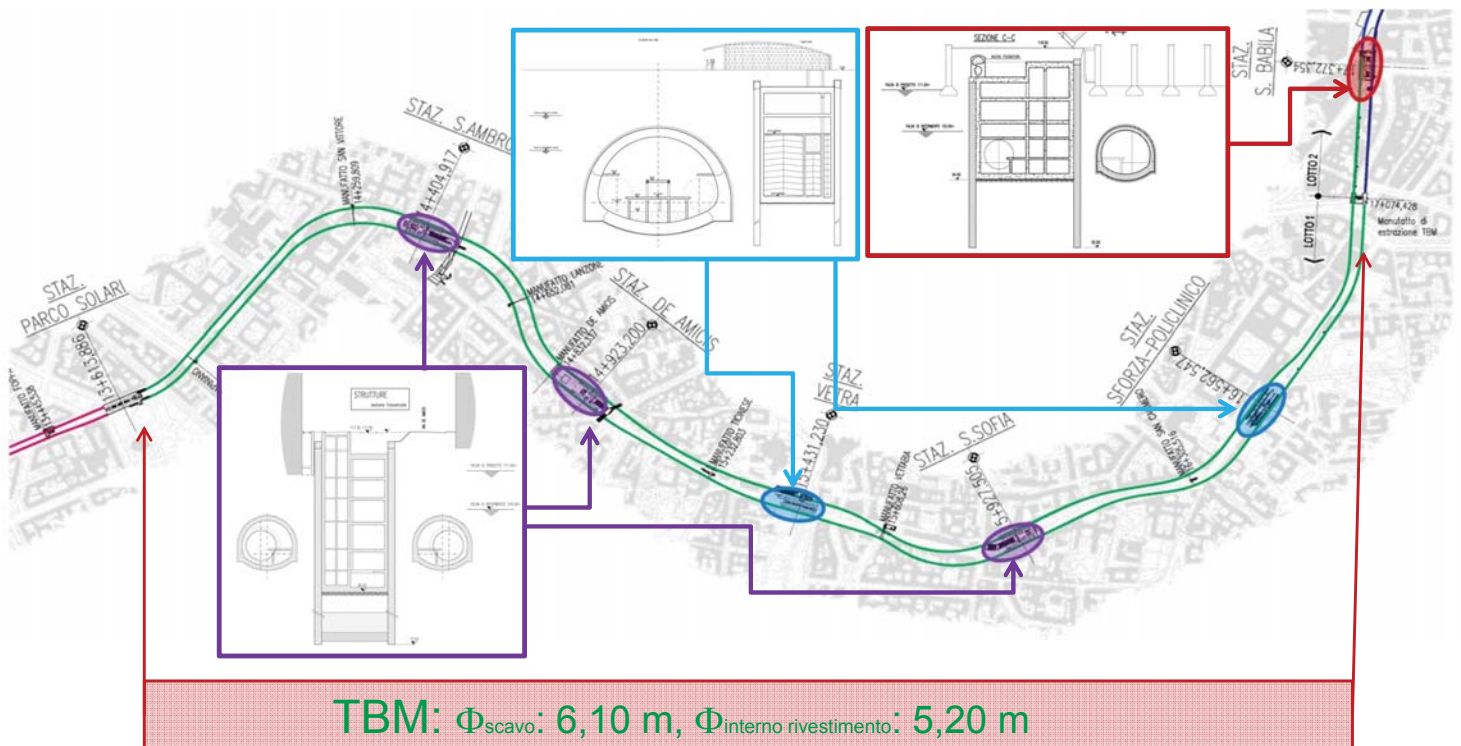
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Comune di Milano



The Tender Project



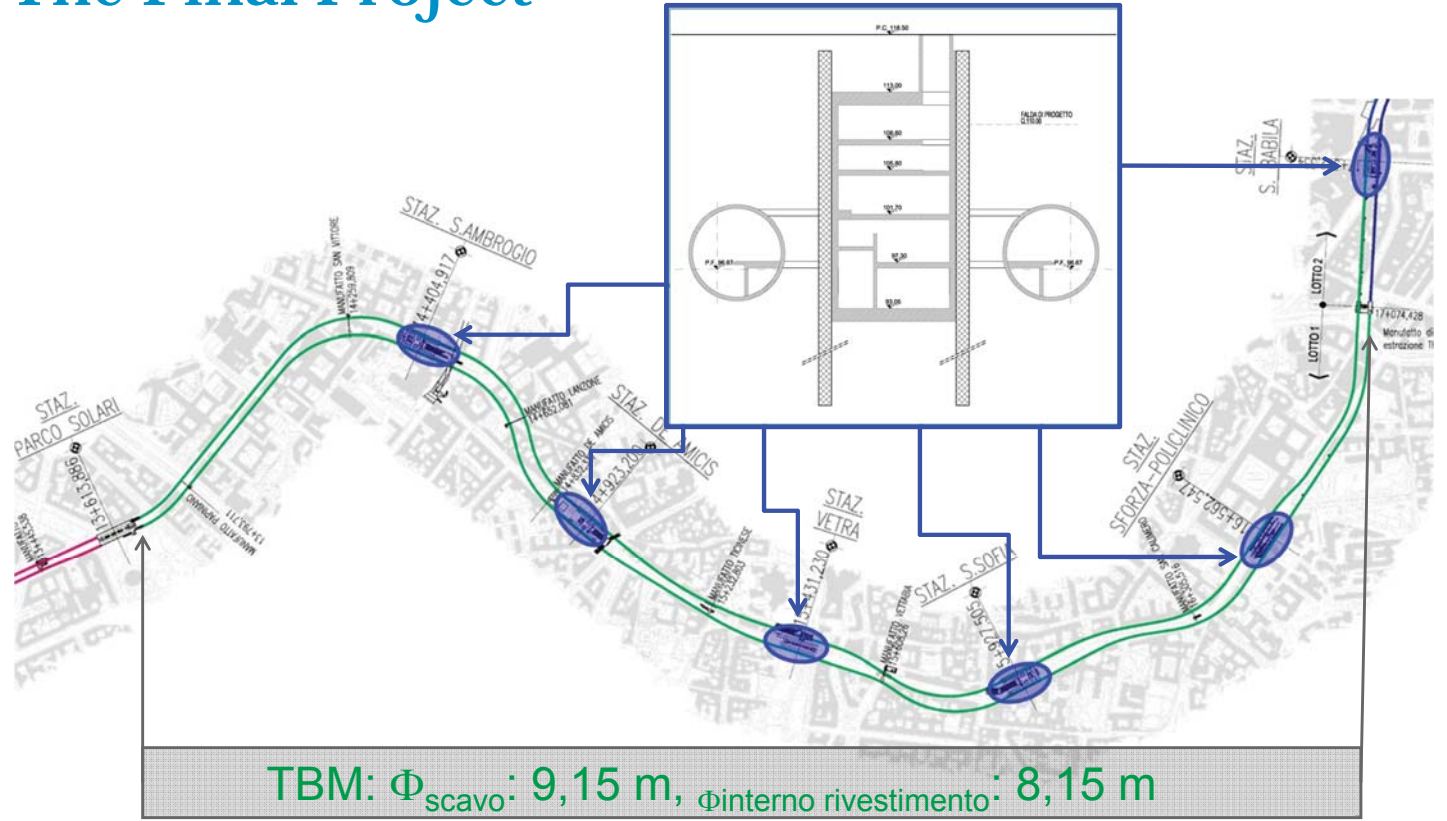
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The Final Project

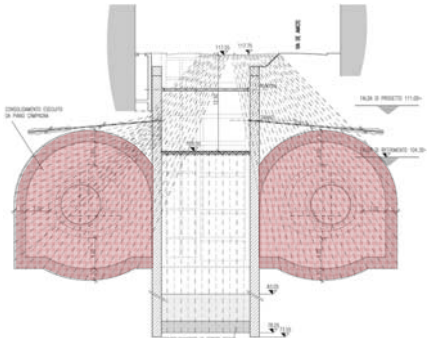


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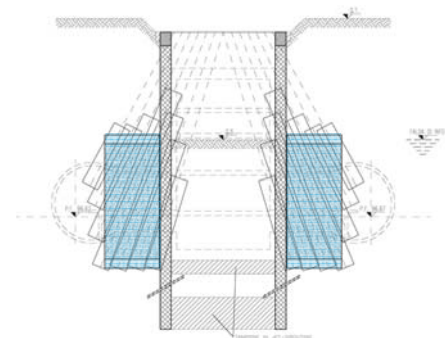


Comparison between Tender and Final Project

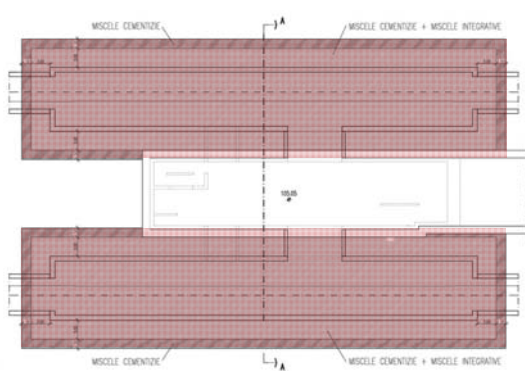
Consolidation section



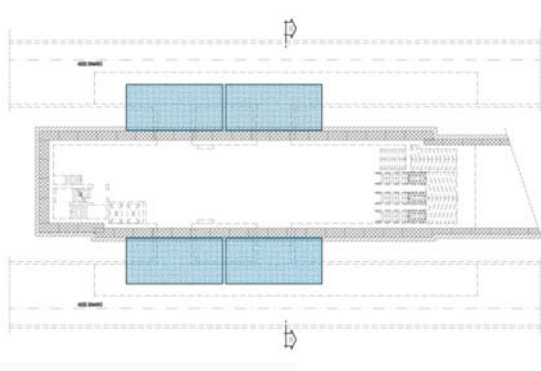
Consolidation section



Consolidation plant



Consolidation plant

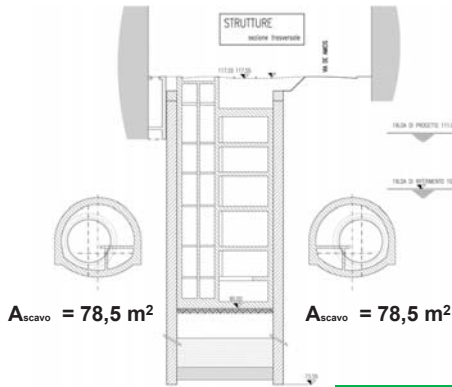


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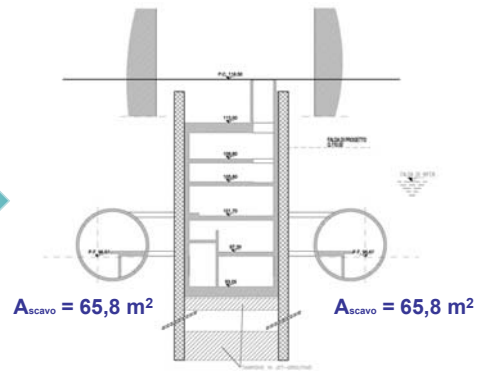


Comparison between Tender and Final Project

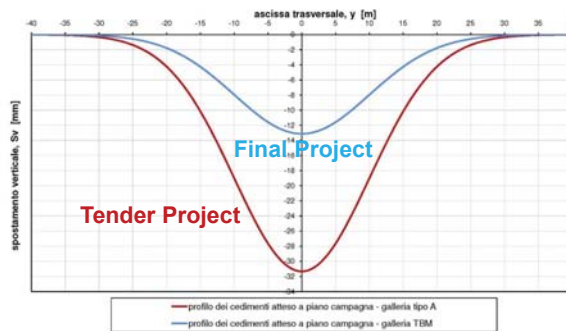
Structure section



Structure section



Settlement diagram



Traditional tunnel

$V_p = 1,0 \%$ (loss volume)
 $D_{sc, eq} = 10 \text{ m}$ (equivalent excavation diameter)
 $k = 0,5$ (shape coefficient)

Mechanized tunnel:

$V_p = 0,5 \%$ (loss volume)
 $D_{sc} = 9,15 \text{ m}$ (excavation diameter)
 $k = 0,5$ (shape coefficient)



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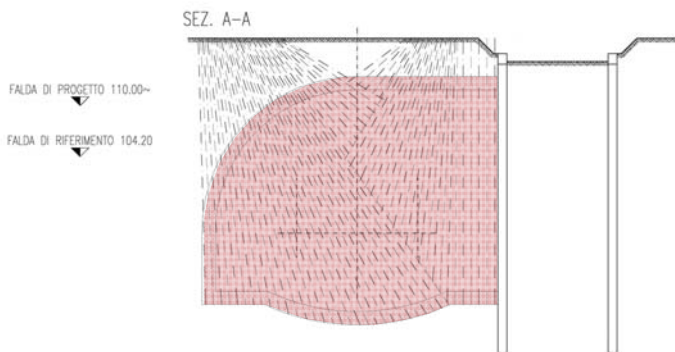
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M4 SPA

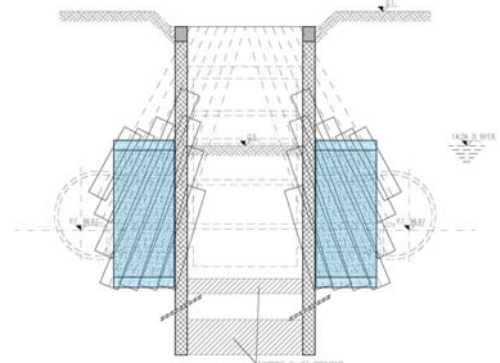


Comparison between Tender and Final Project

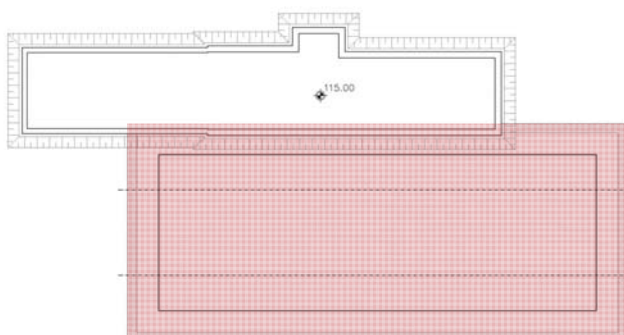
Consolidation section



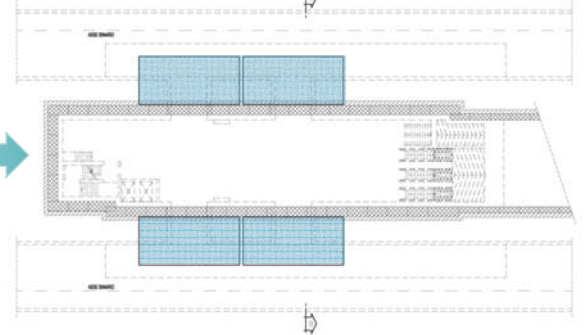
Consolidation section



Consolidation plant



Consolidation plant



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LINEA M4



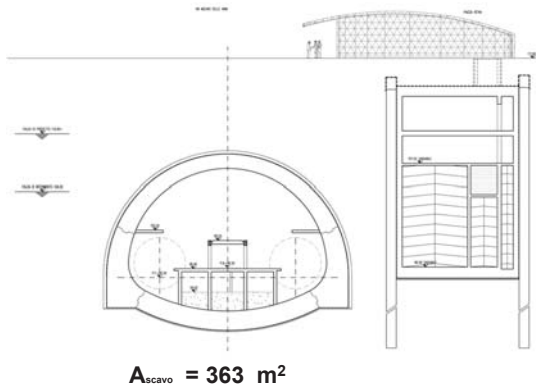
Comune di Milano

M4 SPA

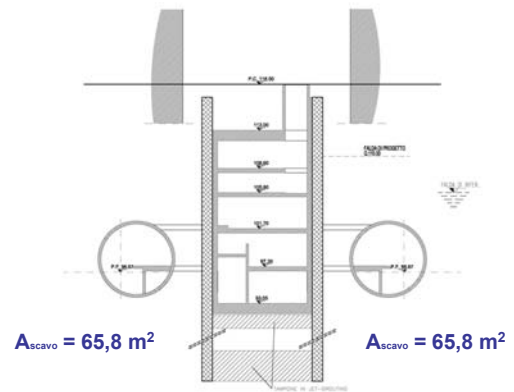


Comparison between Tender and Final Project

Structure section



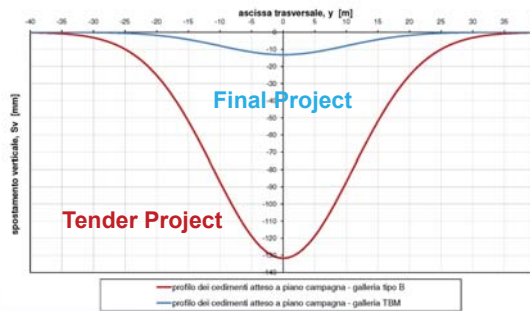
Structure section



Settlement diagram

Taditional tunnel

$V_p = 1,0 \%$ (loss volume)
 $D_{sc, eq} = 21,5 \text{ m}$ (equivalent excavation diameter)
 $k = 0,5$ (shape coefficient)



Mechanized tunnel:

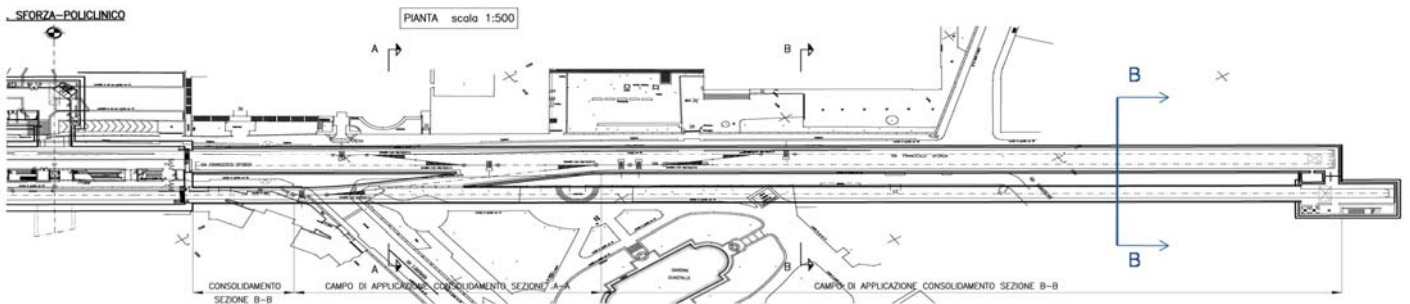
$V_p = 0,5 \%$ (loss volume)
 $D_{sc} = 9,15 \text{ m}$ (excavation diameter)
 $k = 0,5$ (shape coefficient)



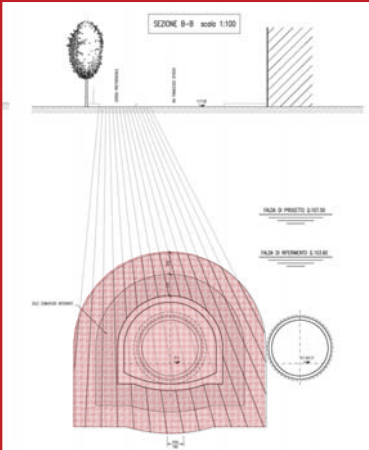
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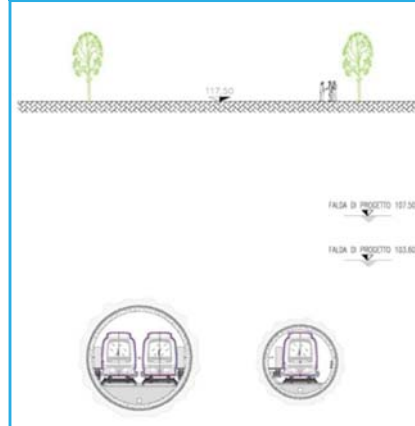
Comparison between Tender and Final Project



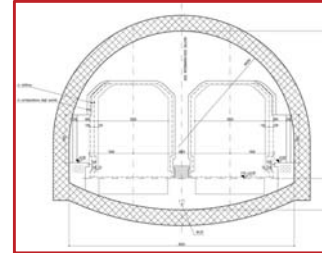
Tender Project



Final Project



Tender Project



Final Project



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Comparison between Tender and Final Project

Naviglio Grande

PIAZZA TIRANA

CANTIERE TBM SAN CRISTOFORO

Piazza Tirana

Cantiere TBM S. Cristoforo

Tender project section

Final Project section

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CONSORZIO MM4

Stations Type

LINE 4

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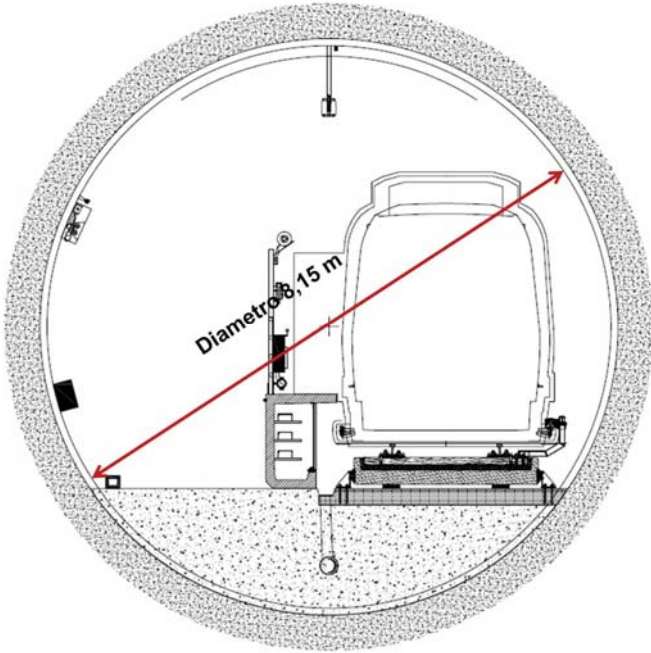
LINEA M4

Milano
Comune di Milano

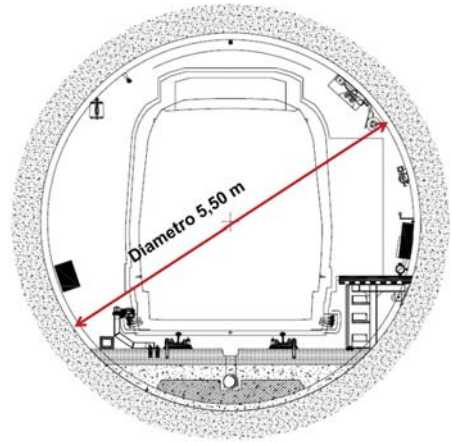
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CONSORZIO MM4

Tunnels Type



TRICOLORE - PARCO SOLARI LINE



EXTERNAL SECTIONS



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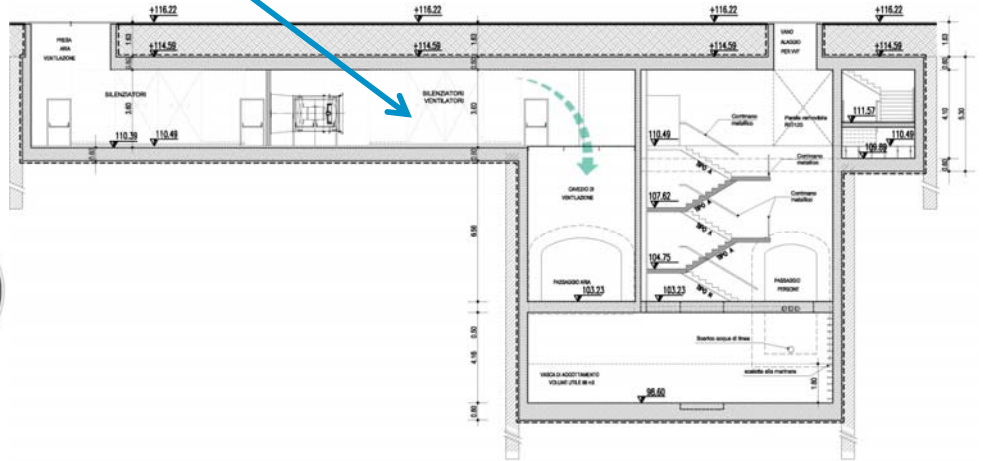
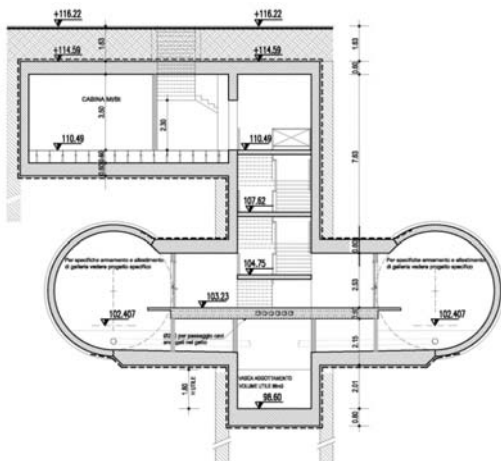
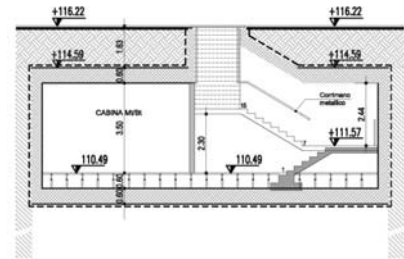
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The Interline Bores

Passengers arrive at the platforms by the ways inside the station.

Technical rooms, tunnel ventilation rooms, transformers rooms and emergency stairs, which can be also fire-evacuation exit, are contained in the **first level** of the interline bores.



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THE TBM

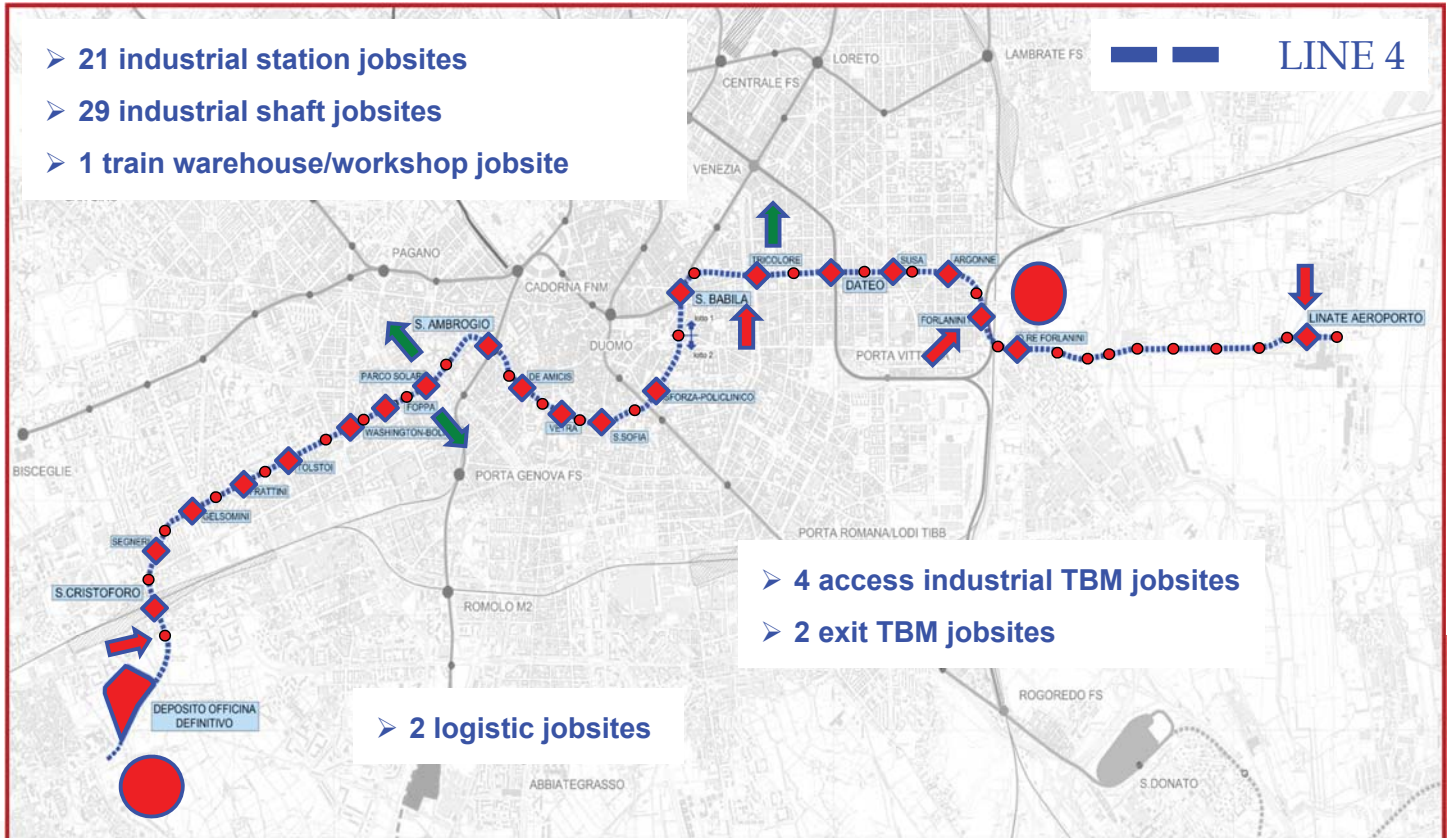


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The Jobsites

- 21 industrial station jobsites
- 29 industrial shaft jobsites
- 1 train warehouse/workshop jobsite

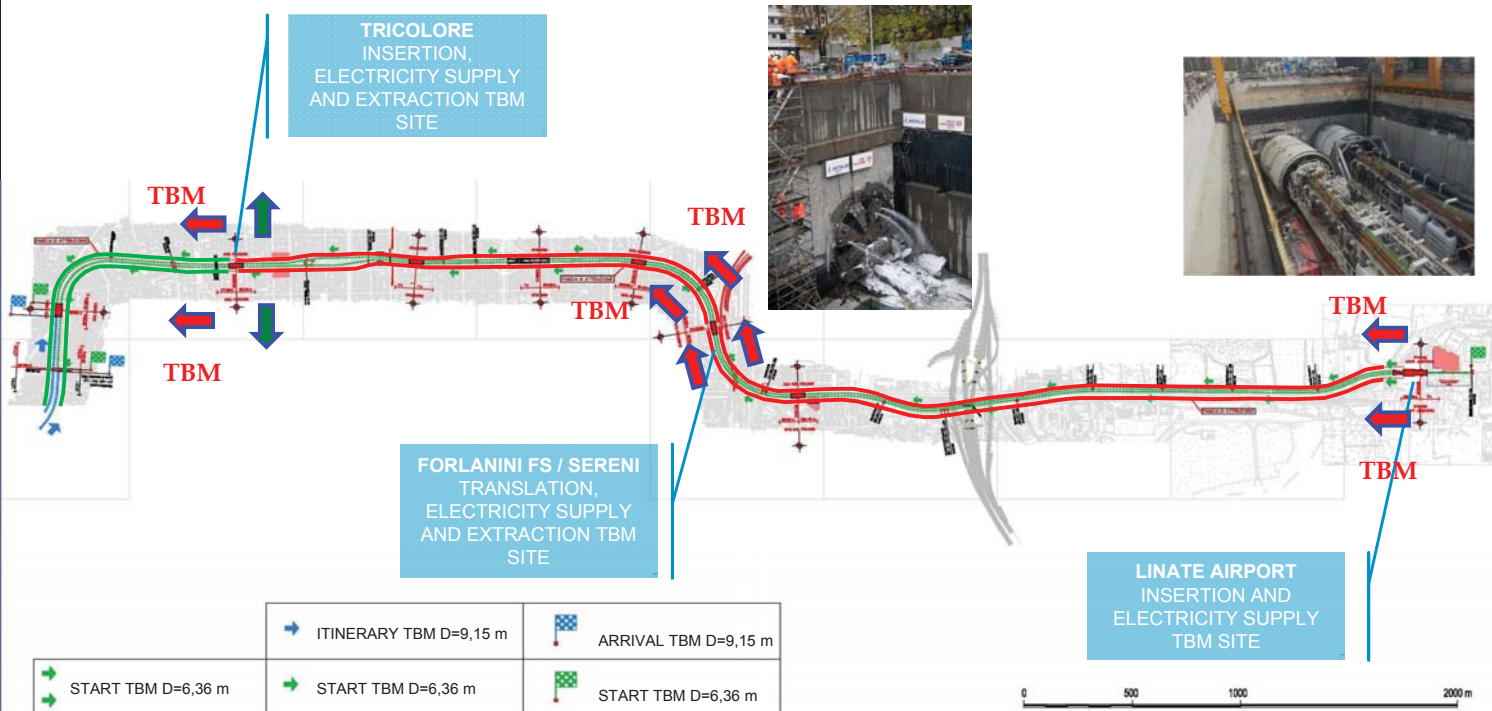


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TBM operational program

Linate-Tricolore line and Tricolore-Solari line



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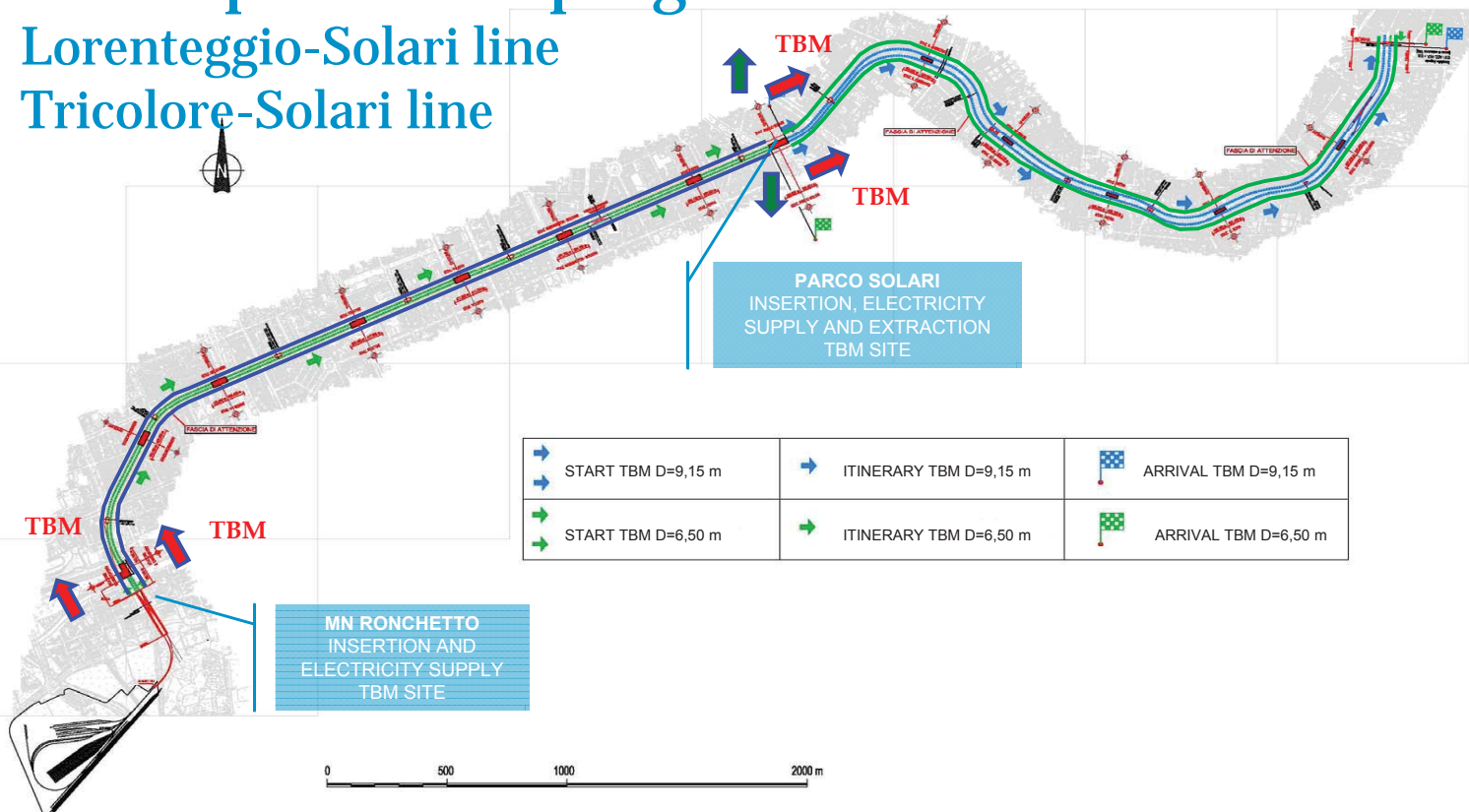
Milano Comune di Milano

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CONSORZIO MM4

TBM operational program

Lorenteggio-Solari line Tricolore-Solari line



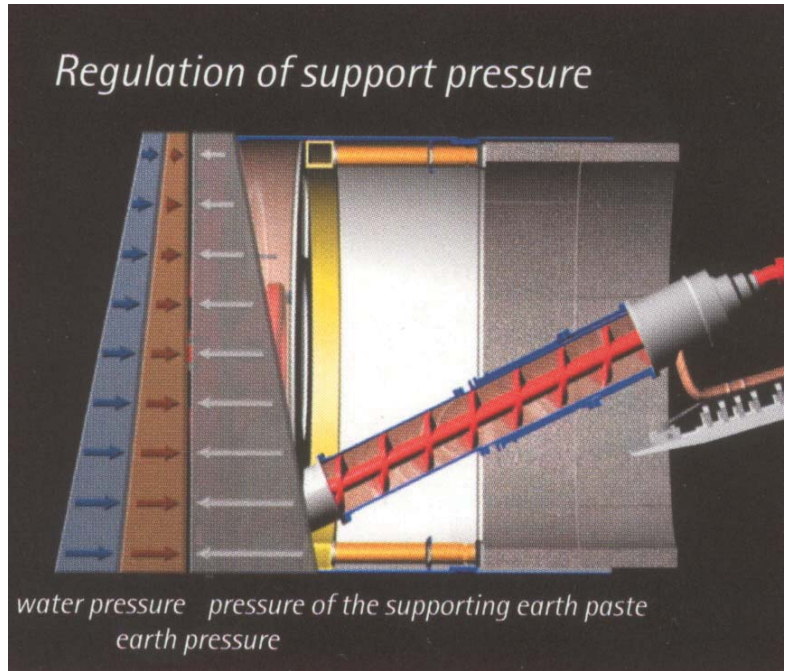
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TBM – EPB Type



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TBM Assembly phases



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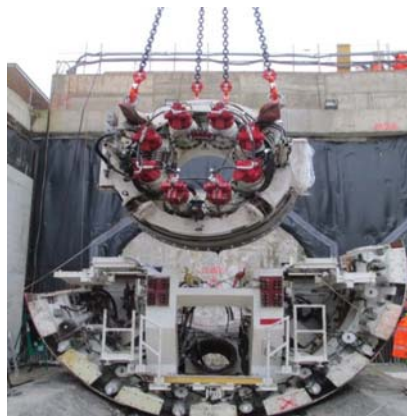
TBM Technical Data

TBM DETAILS :

Factory : Herrenknecht
Model machine : EPB (Earth Pressure Balanced)
TBM Power : 2.000 kVA
TBM + railway car length : circa 106 m
TBM + railway car weight : circa 1090 ton

TUNNEL BORING MACHINE :

Tunnel diameter : 6.340 mm
Weight : circa 53 ton
Tools: 130 (about)
Gap level : 40% (about)
Hydraulic operation : n. 8 engines
Rotations numbers : max 4,50 g/min
Power : 945 kW
Torque : 4.463 kNm (about)



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TBM Characteristics



SHIELD :

Front diameter : 6.310 mm
Back diameter : 6.290 mm
Total length : 8.870 mm (about)
Radius of curvature : 200 m

THRUST FORCE:

2 x 16 jacks
Stroke : 2.200 mm
Thrust force: circa 42.575 KN
Maximum working pressure : 350 bar



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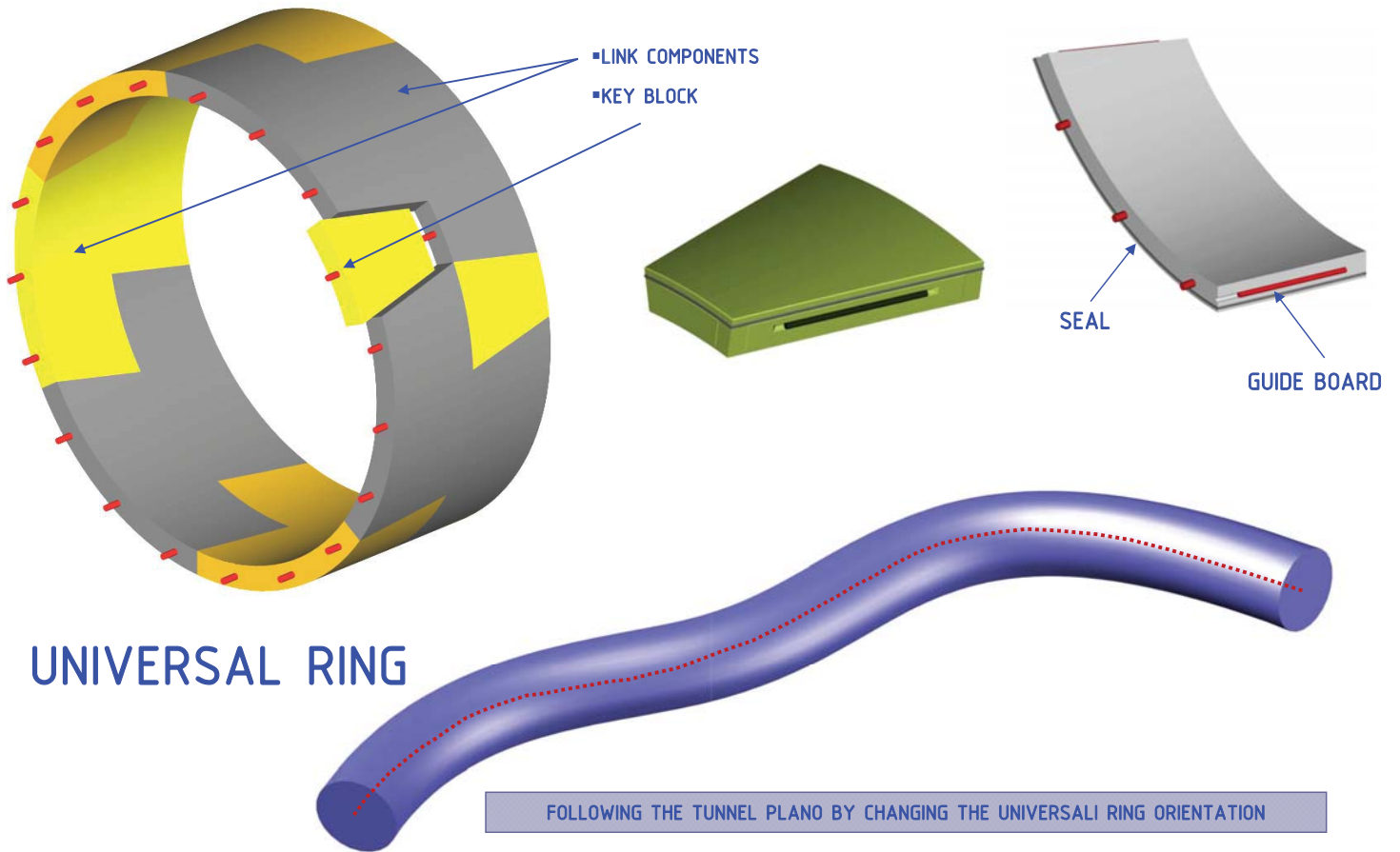
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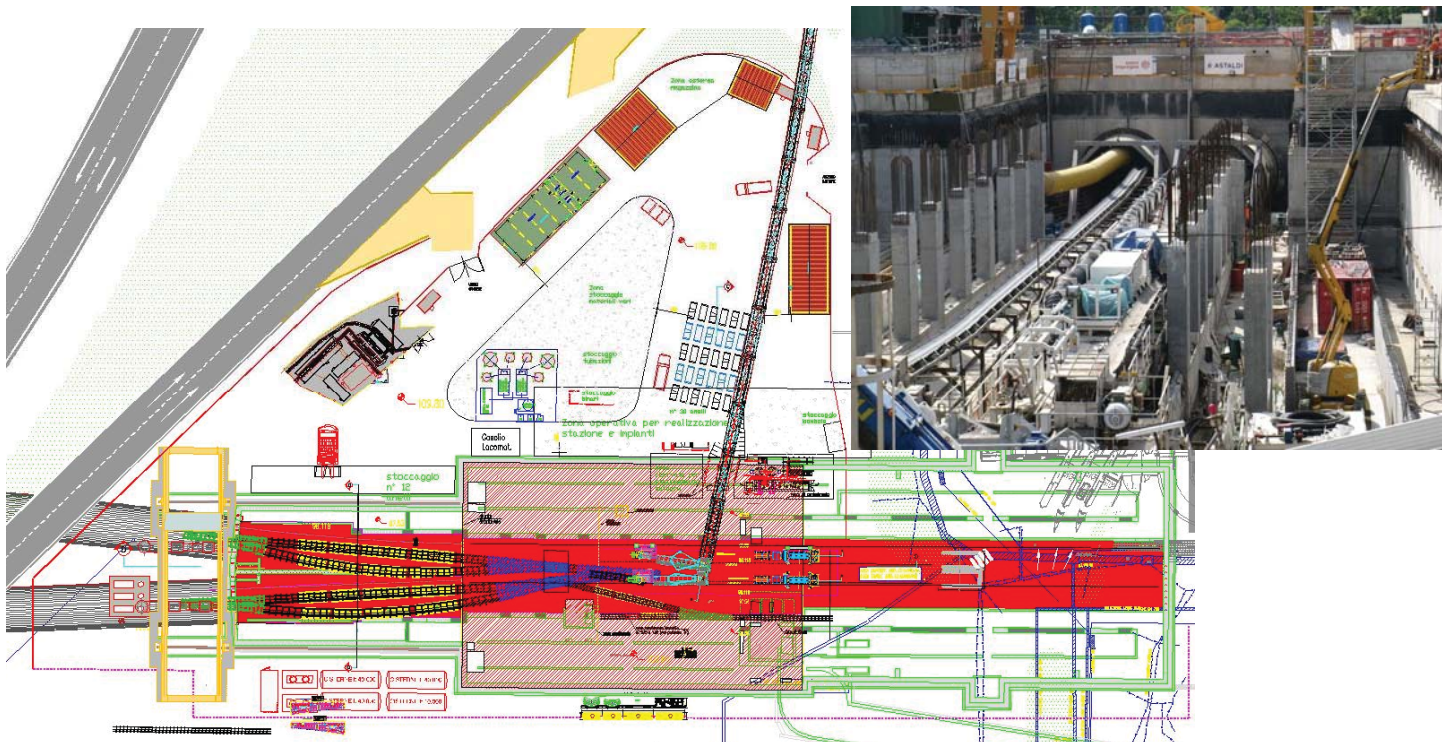
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TBM – Precast Concrete Segmental Lining



Linate TBM Jobsite (Industrial area)



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Linate TBM Logistic Area



Material stock area



Precast stock area



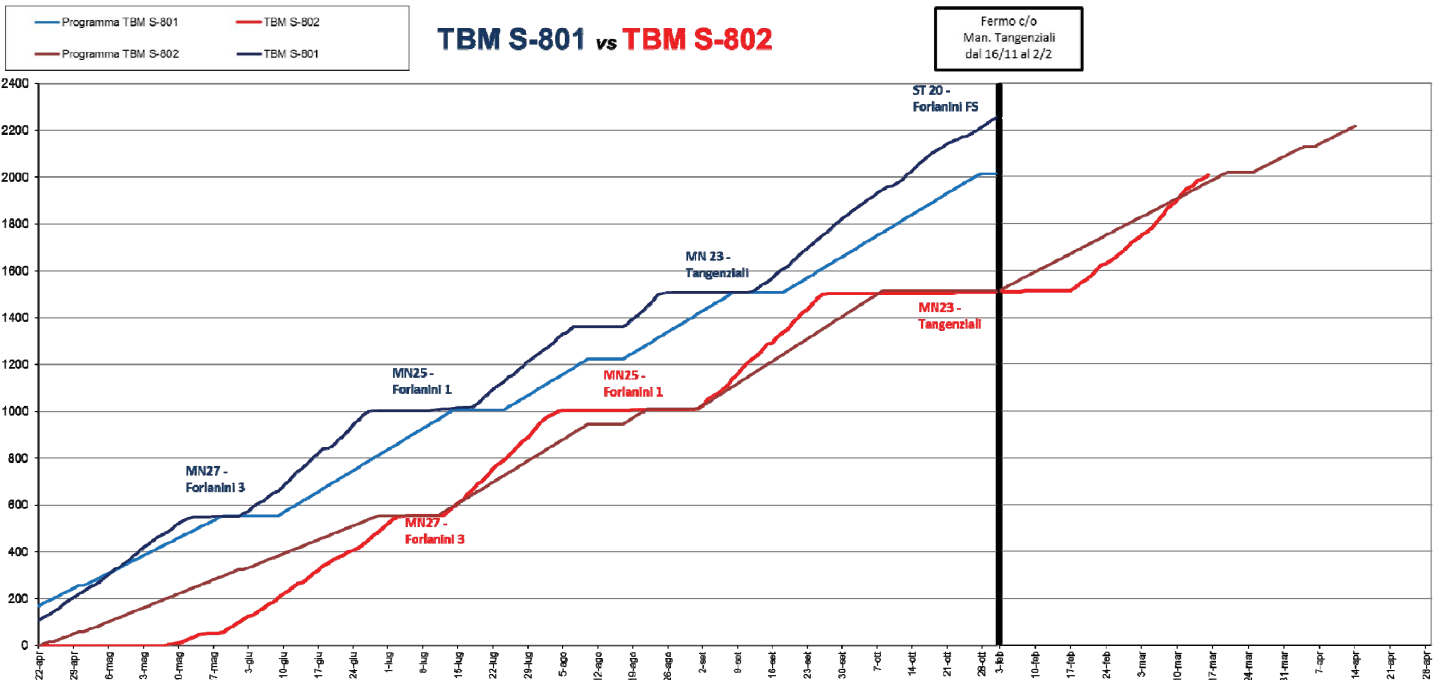
TBM materials stock area



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TBM Product Informations – Yard Linate



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TBM Product Informations – Yard Linate

	TBM S-801	TBM S-802
Tunnel total length	3315 ml	3297 ml
Average production in excavation	19,1 ml/g	21,9 ml/g
Maximum daily advance	35,0 ml	40,6 ml
Weekly maximum advance (7d/24h)	189 ml	211 ml
Monthly maximum advance (7d/24h)	633 ml	800 ml

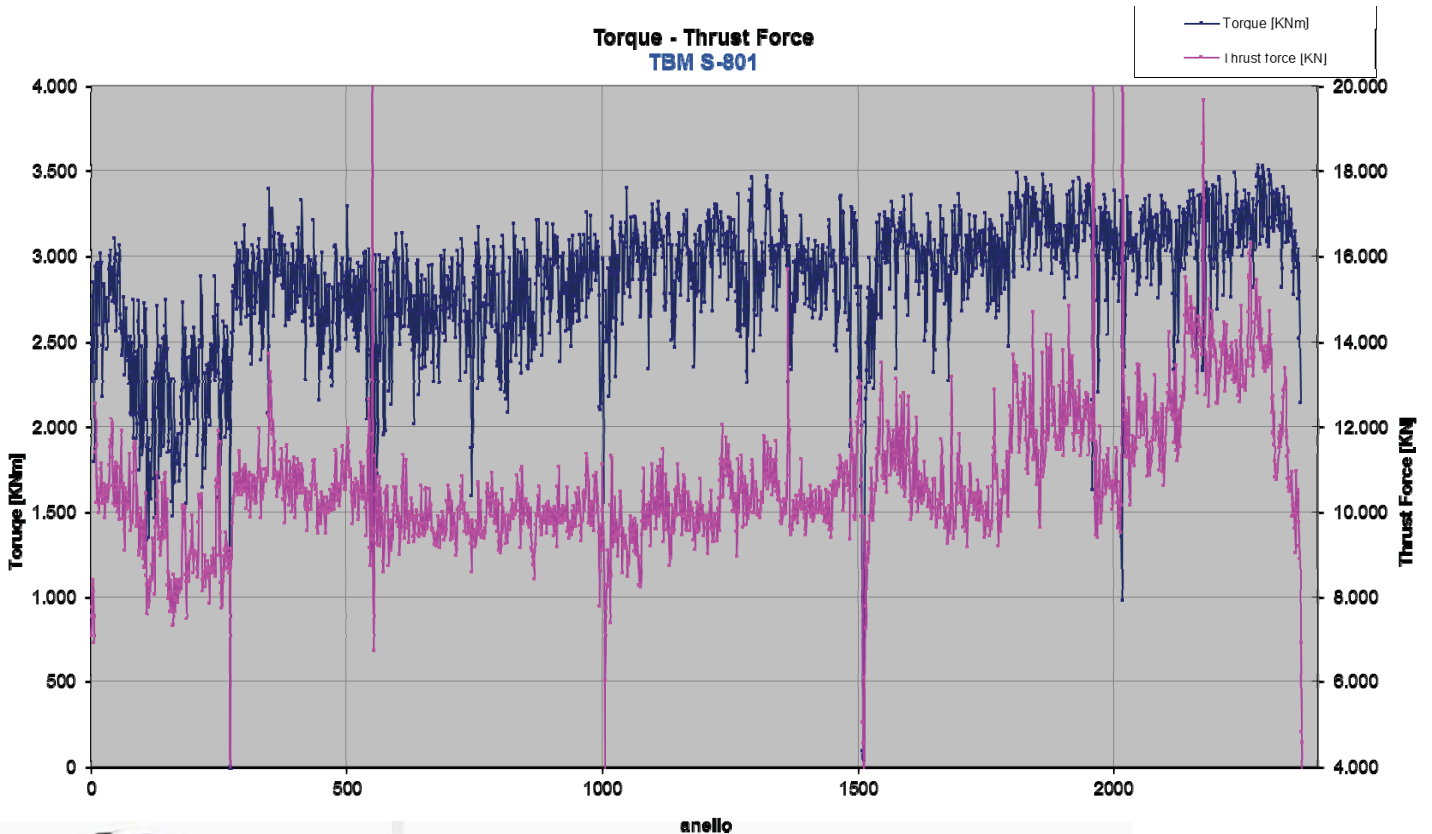


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TBM Advance Performance Information – Linate Jobsite

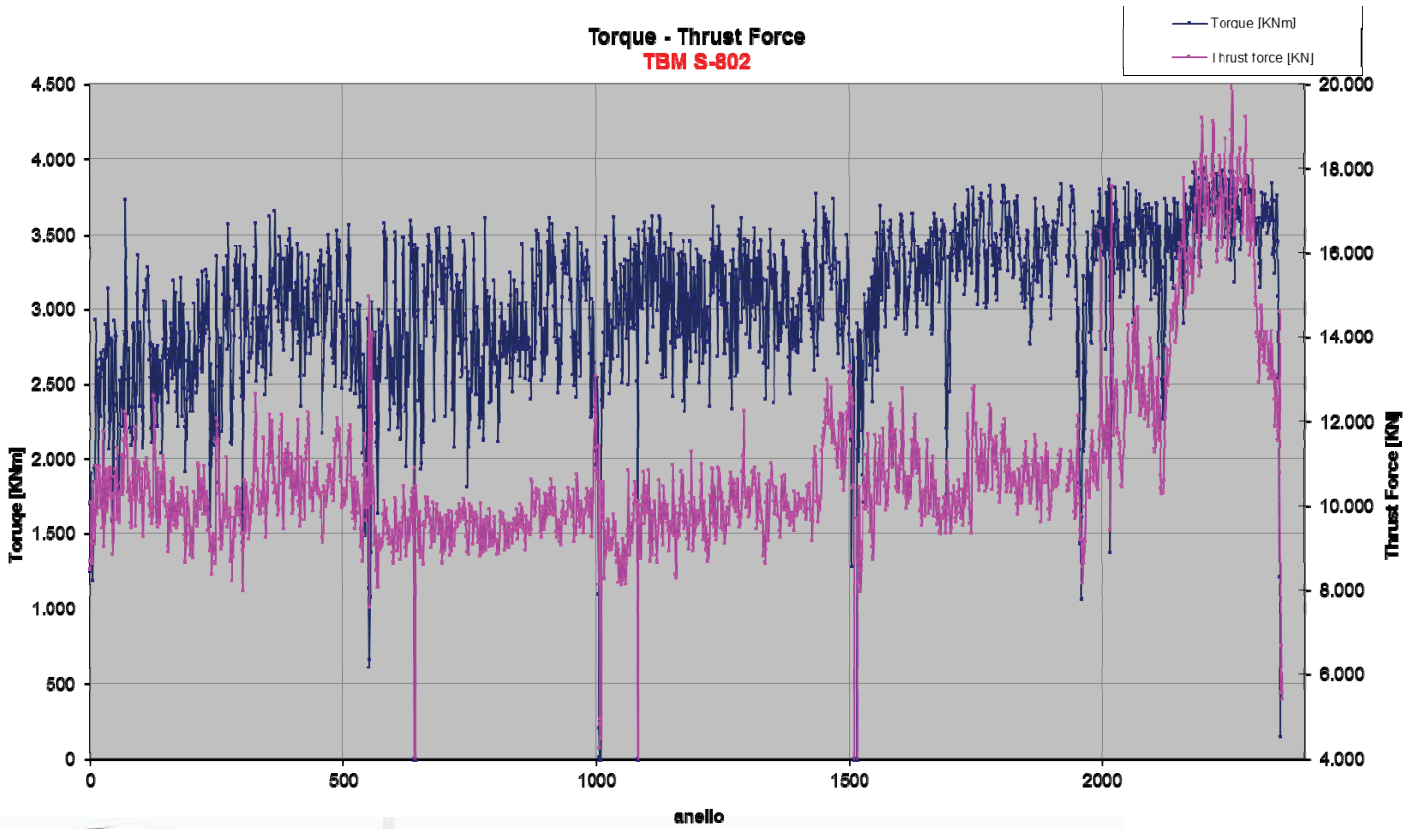
Torque - Thrust Force
TBM S-801



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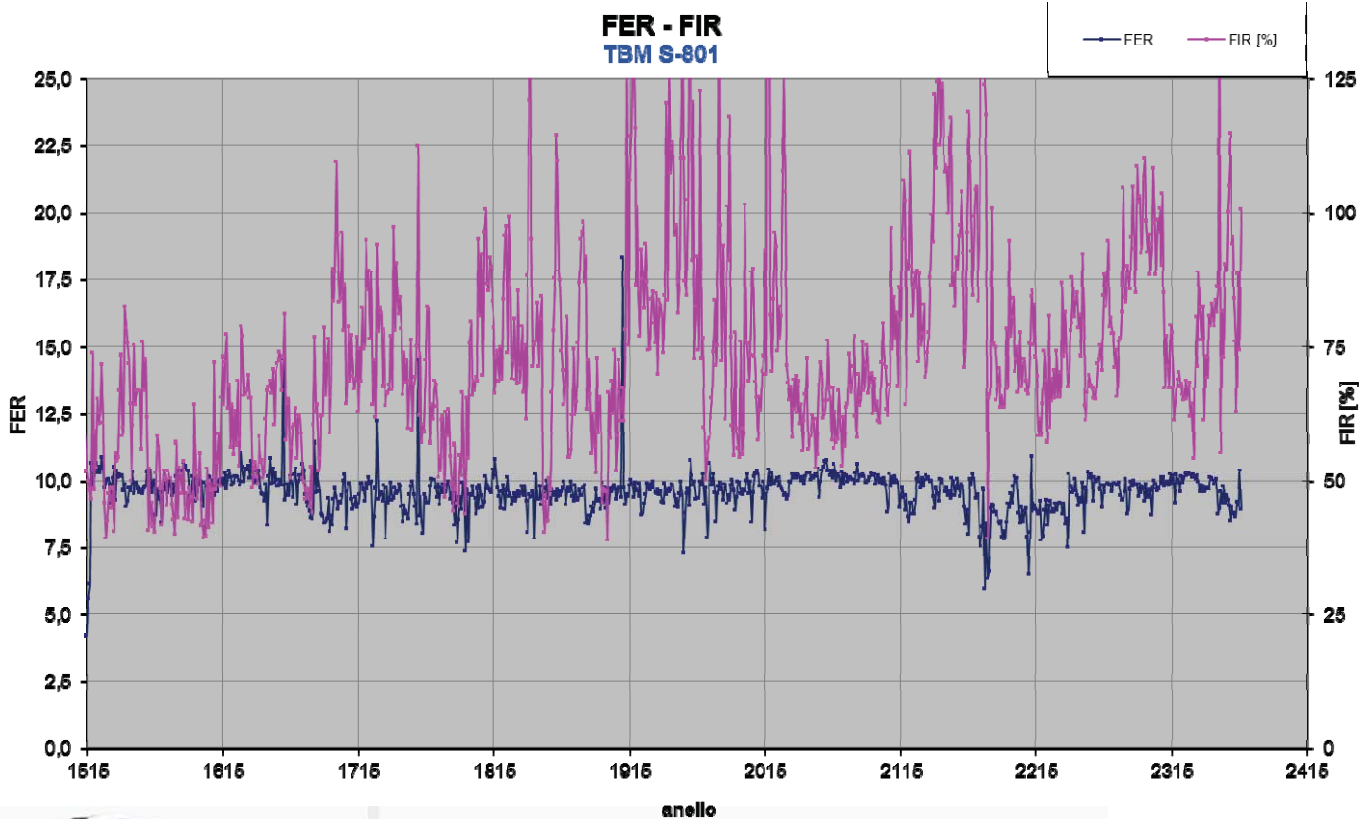
TBM Performance Information – Linate Jobsite



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TBM Soil Conditioning Information – Linate Jobsite

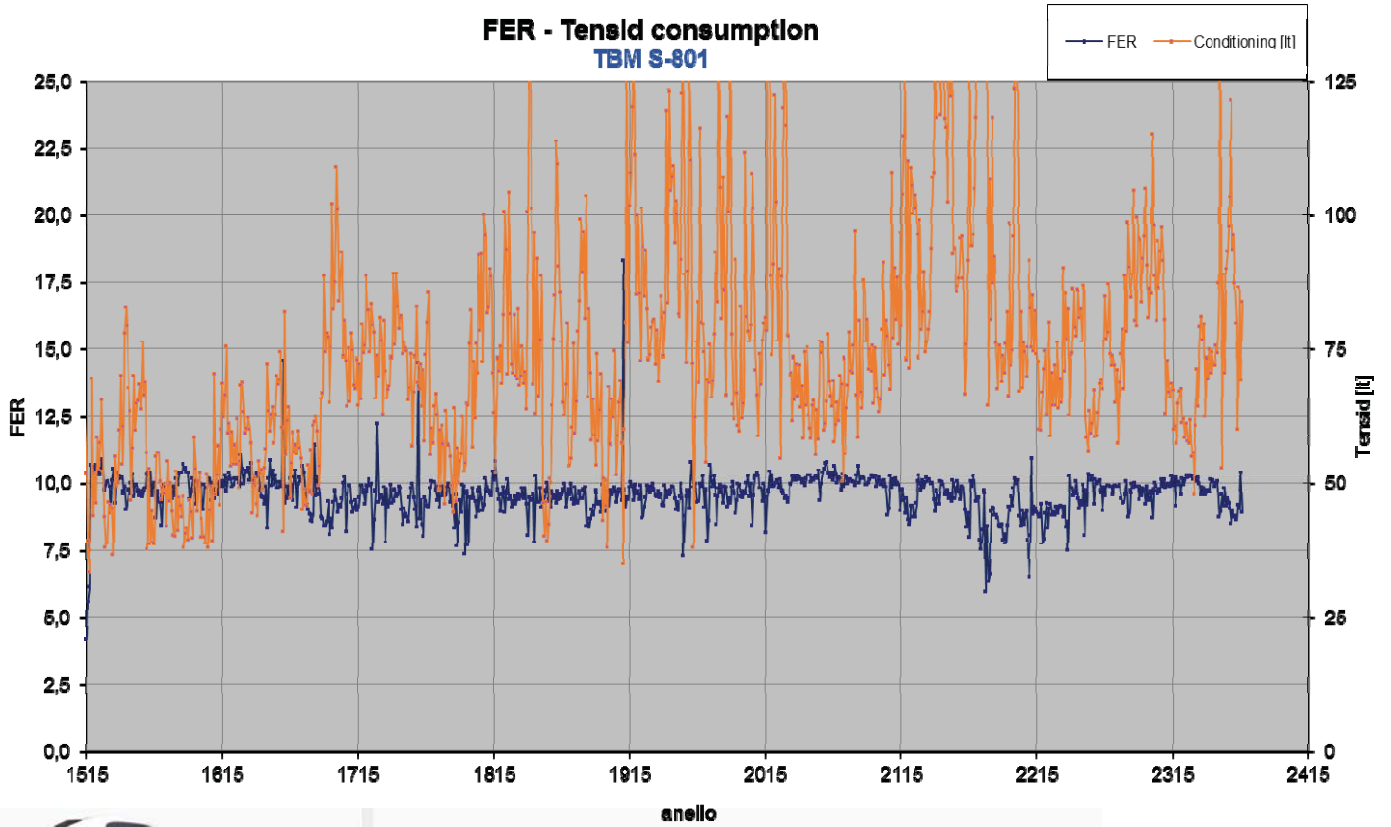


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TBM Soil Conditioning Information – Linate Jobsite

FER - Tensid consumption
TBM S-801

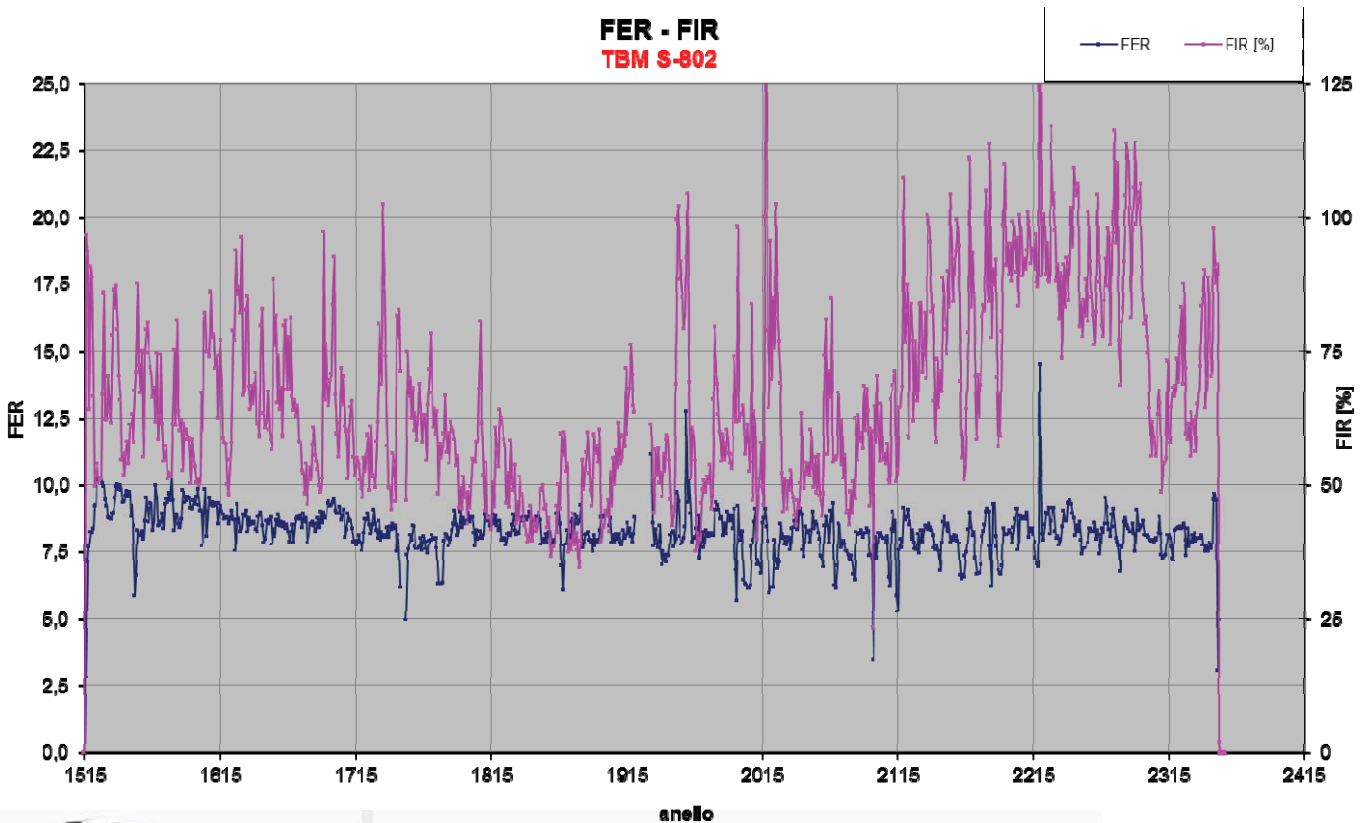


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TBM Soil Conditioning Information – Linate Jobsite

FER - FIR
TBM S-802

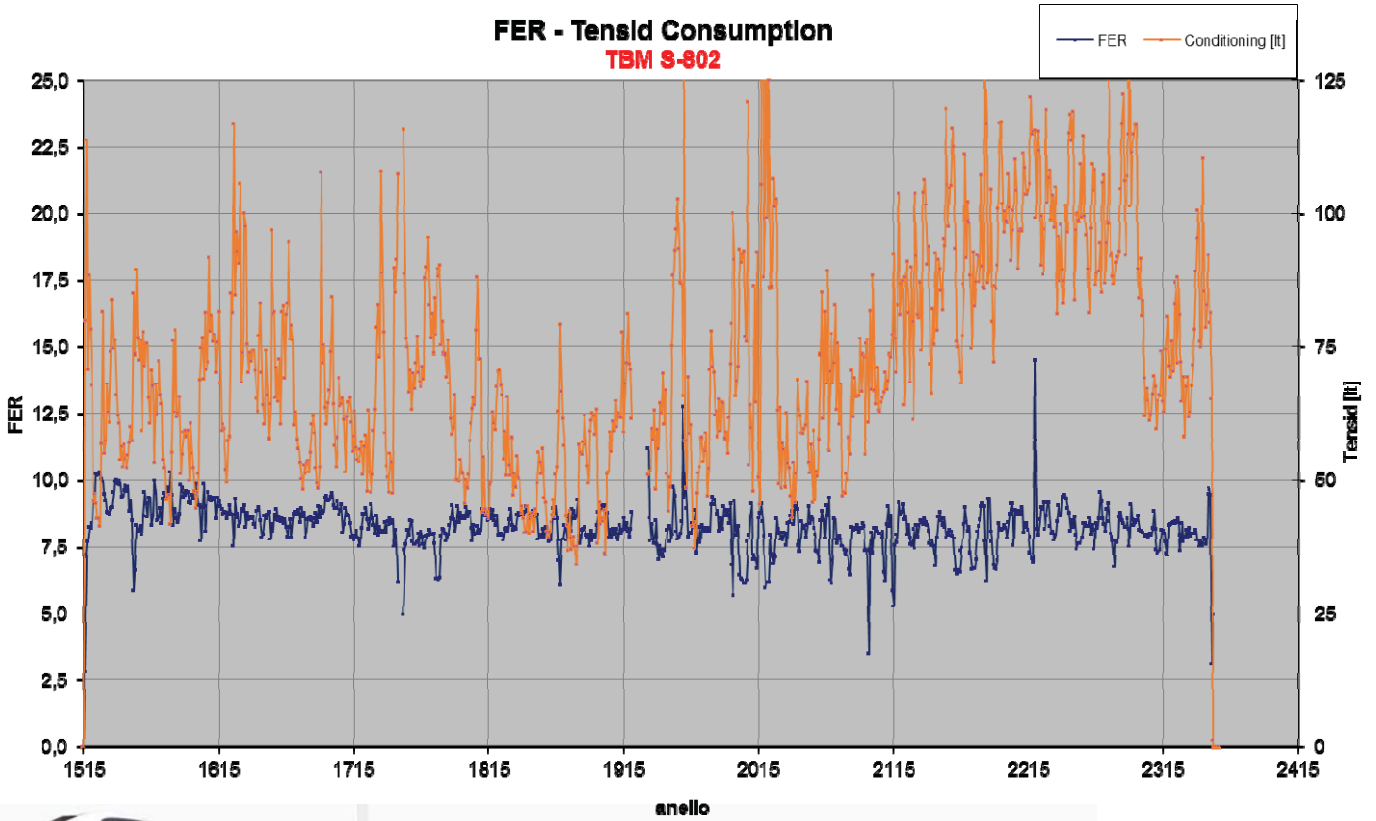


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TBM Soil Conditioning Information – Linate Jobsite

FER - Tensid Consumption
TBM S-802



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TBM Cutterhead Maintenance Information – Linate Jobsite



History of tool substitutions in EXPO Track - TBM S-801 S-802		
TOOL DESCRIPTION	Qty per TBM (nr.)	Total qty of tools per 2 TBMs (nr.)
DISC CUTTERS (1st level of excavation - 175mm)		
Double Disc Cutters (17")	16	142
RIPPERS (2nd level of excavation - 155mm)		
Ripper Head on support [155 mm]	29	204
Ripper Welded [155mm]	4	28
SCRAPERS (3rd level of excavation - 140mm)		
Scraper [140 mm]	66	195
Buckets (Scrapers on gauge)	28	130
PERIPHERAL TOOLS		
GrillBar Rippers (welded)	8	43



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TBM Cutterhead Maintenance – Linate Jobsite



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TBM S-801 Drilling in Forlanini FS (11/11/2014)



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LINEA M4



TBM S-801 Drilling in Forlanini FS (11/11/2014)



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TBM S-802 Drilling in Forlanini FS (10/04/2015)



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Thank you for your attention