TBM Applications III

NORSK FORENING FOR FJELLSPRENGNINGSTEKNIKK

TBM tunnels in extremely difficult geology (shallow tunnels / mixed ground)

3. Challenges in urban infrastructure tunnelling

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Trondheim, 4th Nov 2019

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1. Introduction. Increase of tunnels under urban environment

TRANSPORTATION

Key Trends

Saturated and congested transportation assets

Rise of energy efficient and pollution free solutions

Urban mobility demand is booming: from 30 tn passenger-km/year to **50 tn** in 2050

High-speed trains are **x8** more energy-efficient than planes and **x4** than cars

50% of the world's top 100 airports will have capacity constraints by 2025

Consequences

Roads: capacity expansion, access to cities

Rails: inter-city connections

Urban transportation: Trams, LR, Metro

Expansion of existing **Airports**, new airports

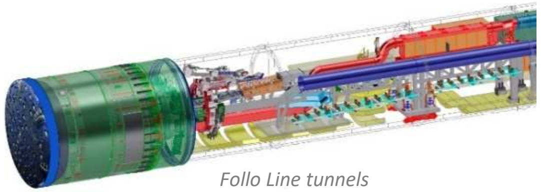
- Global growth impacts large-scale urban regions, in particular their attractiveness.
- Land expansion occurs at the edge of existing urban areas and cities have to adapt and change by investing in transport infrastructure to strengthen inner urban development or “city-to-city” connections, despite difficult ground conditions.
- Urban tunnels are at the core of urban expansion management. That´s why tunnels under urban environment is a constant demand from clients around the world.
- TBMs are one of the potential tunnel construction methodology that can be applied with a successful performance.
- Minimizing interference in surface, impact or disturbance to the communities and stakeholders along the tunnel alignment and optimizing cost and time for clients.

2. Type of TBM machines. To choose the right one

- **Main Beam**
  (Working in open mode)
- **Single Shield**
  (Working in open and close mode)
- **Double Shield**
  (Working in open mode)
- **Earth Pressure Balance (EPB)**
  (Single Shield working in close mode)
- **Slurry Shield**
  (Single Shield working in close mode)

Oliola tunnel

Camarillas tunnel

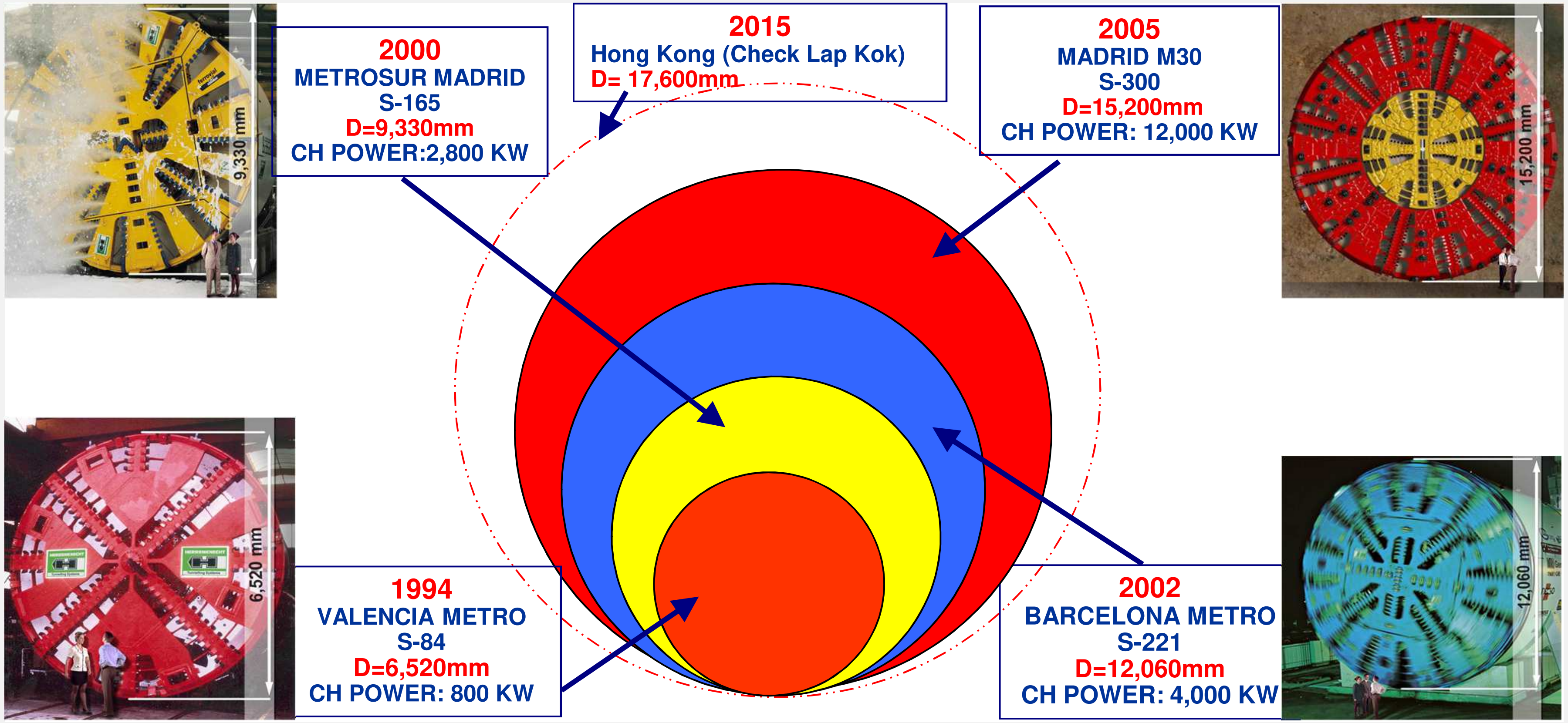


Follo Line tunnels

Barcelona Metro Line 9

Santoña tunnel

TBM Applications III



NFF NORSK FORENING FOR FJELLSPRENGNINGSTEKNIKK

TBM Applications III

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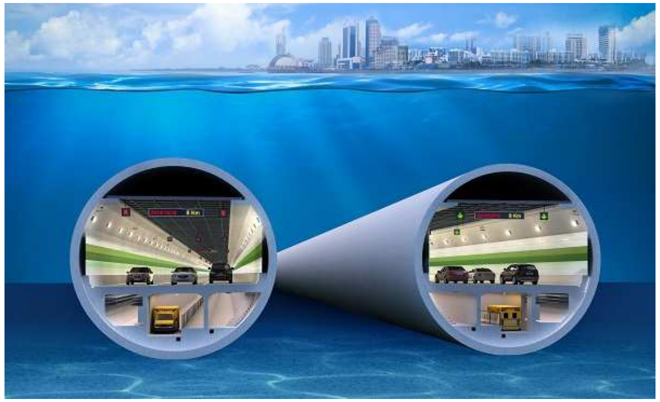
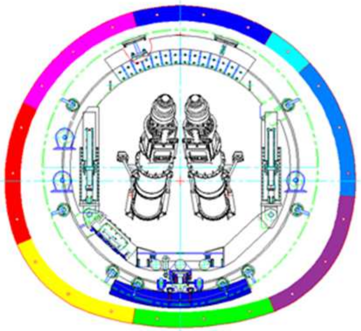
Start date/ Launch	Country	Project	TBM manufacturer	Diameter
Design started 2009	Russia	Orlovsky Tunnel, Saint Petersburg*	1 Herrenknecht Mixshield Project on hold	19.00m
2015	Hong Kong	Tuen Mun - Chek Lap Kok subsea highway link*	1 Herrenknecht Mixshield	17.60m
2011	USA	Alaskan Way highway replacement tunnel*	1 Hitachi Zosen EPBM	17.48m
2016	Italy	Santa Lucia Highway Tunnel, A1 near Firenze*	1 Herrenknecht EPBM	15.87m
2018	China	Shenzhen Chunfeng Tunnel Wuhan Metro road/metro river crossing*	1 CREG Slurry	15.80m
2019	Australia	West Gate Tunnel (Melbourne) A1 Sparvo highway tunnel*	2 Herrenknecht EPB	15.60m
2006	China	Shanghai Changjiang under river highway tunnel Shanghai West Changjiang Yangtze	2 Herrenknecht Mixshields	15.43m
2011	China	Hangzhou Qianjiang Under River Tunnel	Ex-Shanghai Changjiang highway tunnel Project	15.43m
2005	Spain	Madrid Calle 30 Highway Tunnels	2 machines	15.20m
2017	China	Shantou City Su'ai Subsea Highway Tunnel Caltanissetta highway tunnel, Sicily*	1 CREG Slurry	15.03m
2013	China	Shouxhiou Lake Highway Tunnel	1 Herrenknecht Mixshield	14.93m
2011	China	Weisan Road Tunnel, Nanjing* Shanghai Hongmei Road	2 IHI/Mitsubishi/CCCC slurry TBMs	14.93m
2008	China	Nanjing Yangtze River Tunnel* Jungong Road Subaqueous Tunnel, Shanghai	2 Herrenknecht Mixshields	14.93m

Start date/ Launch	Country	Project	TBM manufacturer	Diameter
2004	China	Shangzhong Road Subacqueous	1 NFM Technologies	14.87m
2000	The Netherlands	Groenehart double-track rail tunnel Waterview highway connection, Auckland*	1 NFM Technologies	14.87m
2009	China	Yingbinsan Road Tunnel, Shanghai Bund Tunnel, Shanghai	1 Mitsubishi EPBM Ex-Bund Tunnel machine	14.27m
2006	Canada	Niagara Water Diversion Tunnel*	1 Robbins hard rock gripper TBM	14.40m
2004	Russia	Moscow Silberwald Highway Tunnel	1 Herrenknecht Mixshield	14.20m
2001	Russia	Moscow Lefortovo Highway Tunnel*	1 Herrenknecht Mixshield	14.20m
1997	Germany	Hamburg 4th Elbe River Highway Tunnel* Tokyo Metro	1 Herrenknecht Mixshield	14.20m
1994	Japan	Trans Tokyo Bay Highway Tunnel	8 machines	14.14m
2010	Spain	Seville SE-40 Highway Tunnels*	2 NFM Technologies EPBMs	14.00m

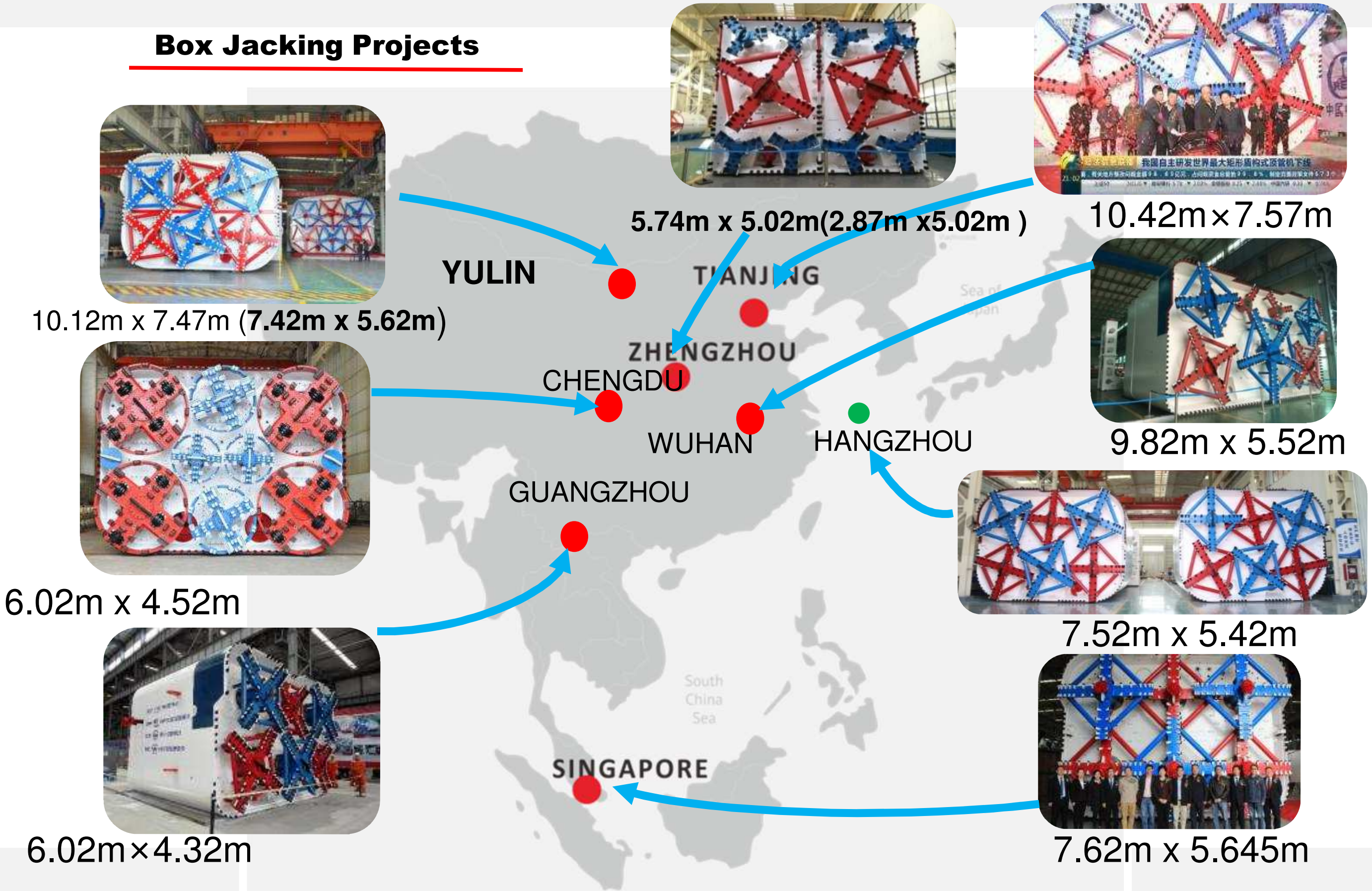




11.9×10.95m Horse-shoe Shape EPB TBM Railway Tunnel

Box Jacking Projects



3. Common Challenges in urban infrastructure tunnels

Topics for the symposium:

- Easy tunnels are already built
- Future machines, innovations and markets
- Groundwater handling
- Shallow tunnels

3.1. Shallow tunnel launch portal (Dubai, UAE)

METRO DUBAI 2020

CONTRACTOR: Expolink consortium (Alstom - ACCIONA - Gülermak)

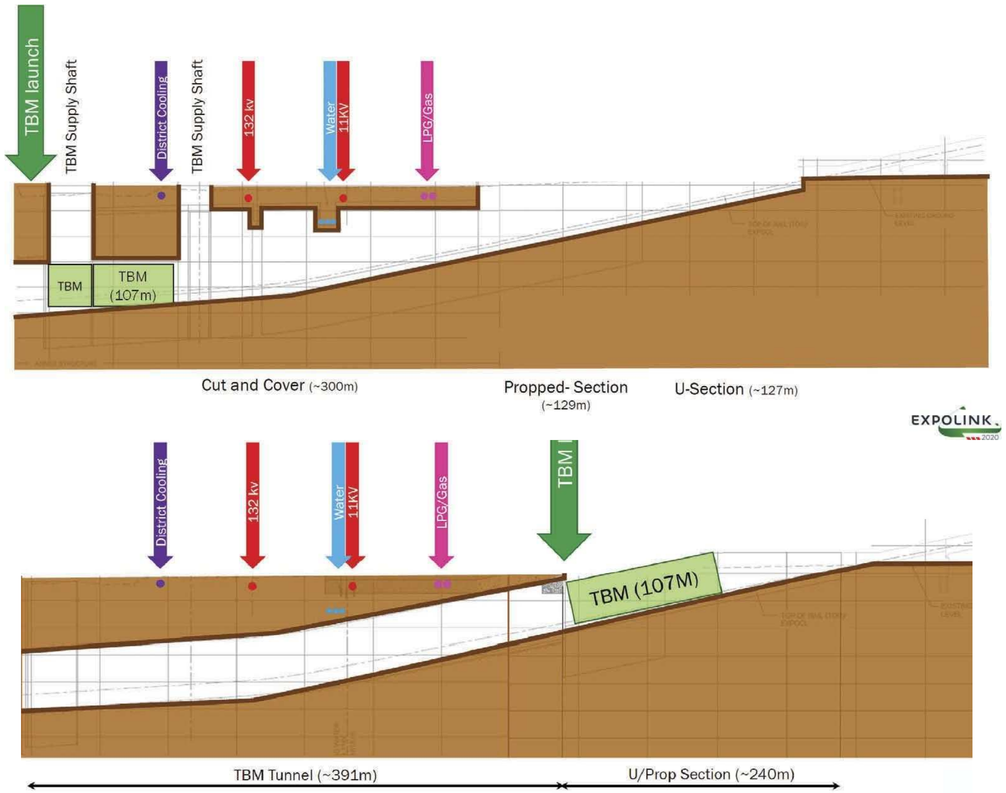
CLIENT: RTA- Roads & Transport Authority Dubai.

CONTRACT VALUE: 26 B NOK

SCOPE: 15 Km tram (11.8 km elevated, 3.2 km underground (TBM D=6.9 m)). – 7 stations including Expo

Reference design:

- Classic cut and cover ramp approach leading to the TBM launch site.
- 560m of below grade ramp section (300m as cut and cover)
- Two TBM supply shafts were provisioned.



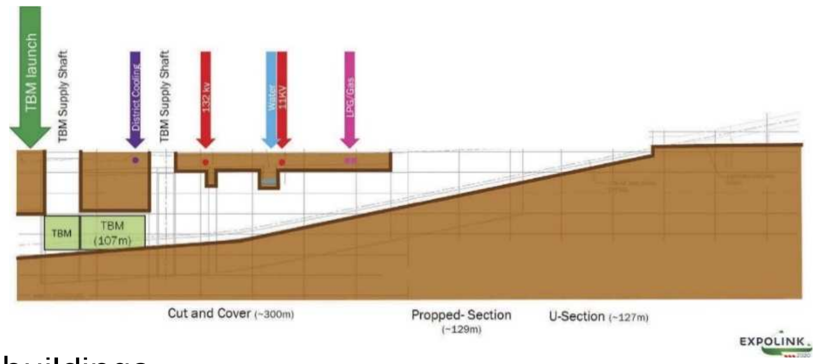
Alternative design proposed:

- Shallow launch of the TBM
- Cut and cover section replaced with a bored tunnel constructed with minimum cover requirements

Reference design:

Opportunities:

- Construction ahead of TBM delivery possible although on the critical path
- Final structure provides more space for Mechanical, Electrical and Plant equipment (MEP)
- Reduced geotechnical risk profile



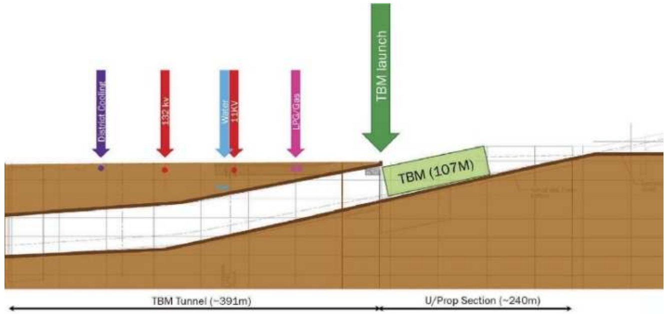
Risks:

- Multiple stakeholder approvals required
- Three major utility diversions
- Large construction area required close to residential buildings
- Complex construction works that lie on the critical path of the project
- Complex dewatering requirements
- Utility corridor largely compromised for future development (major utility corridor cross-ing alignment)

Reference design:

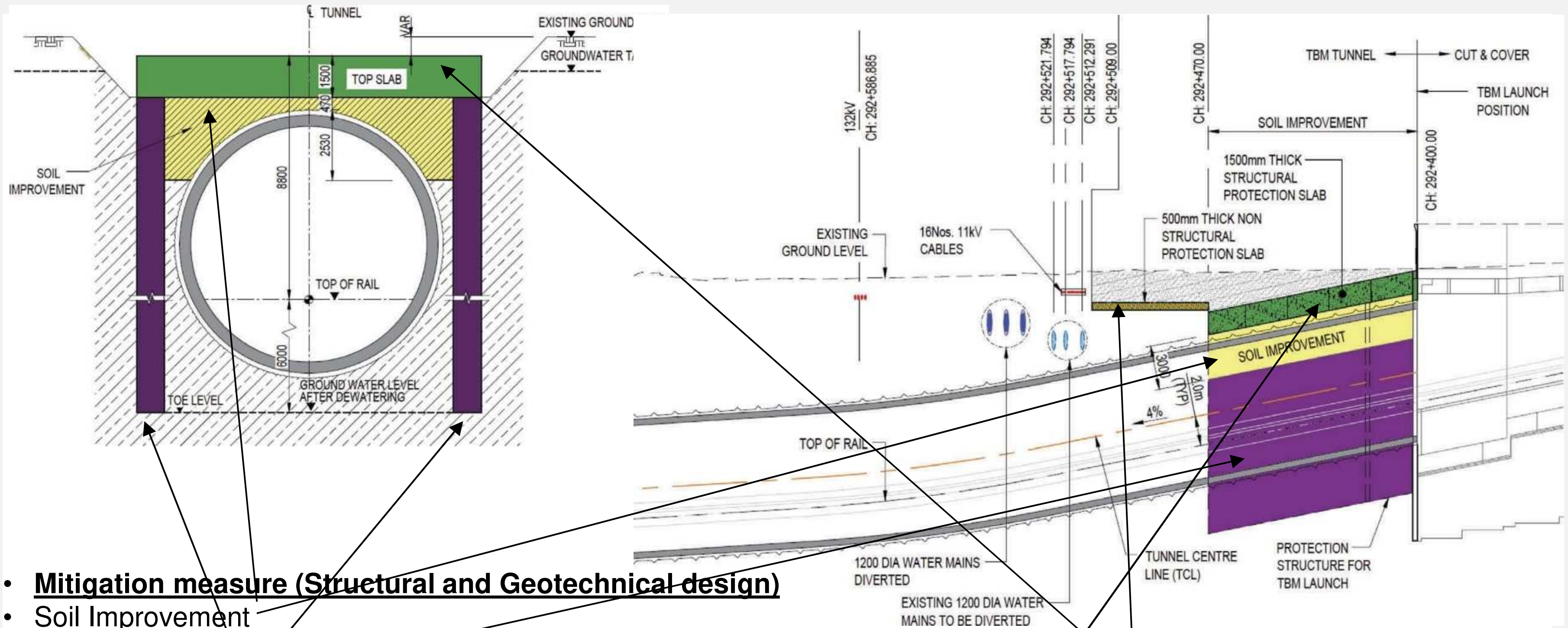
Opportunities:

- Major utility diversions can be avoided
- Reduced stakeholder approval risk
- Utility corridor remains available for future developments
- Start of the open cut works and the provision of the required protection works for the TBM launch provides more float on critical path of the project
- Reduced soil subsidence from tunnelling compared to cut and cover and decrease in influence zone of settlement

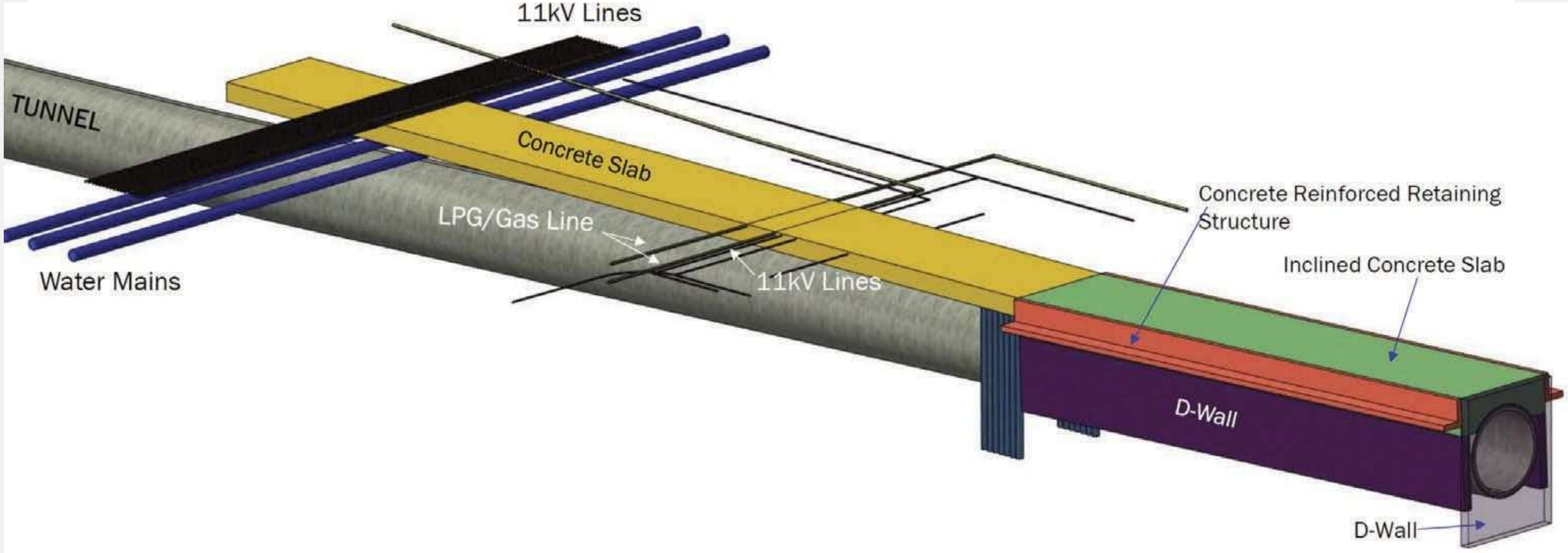


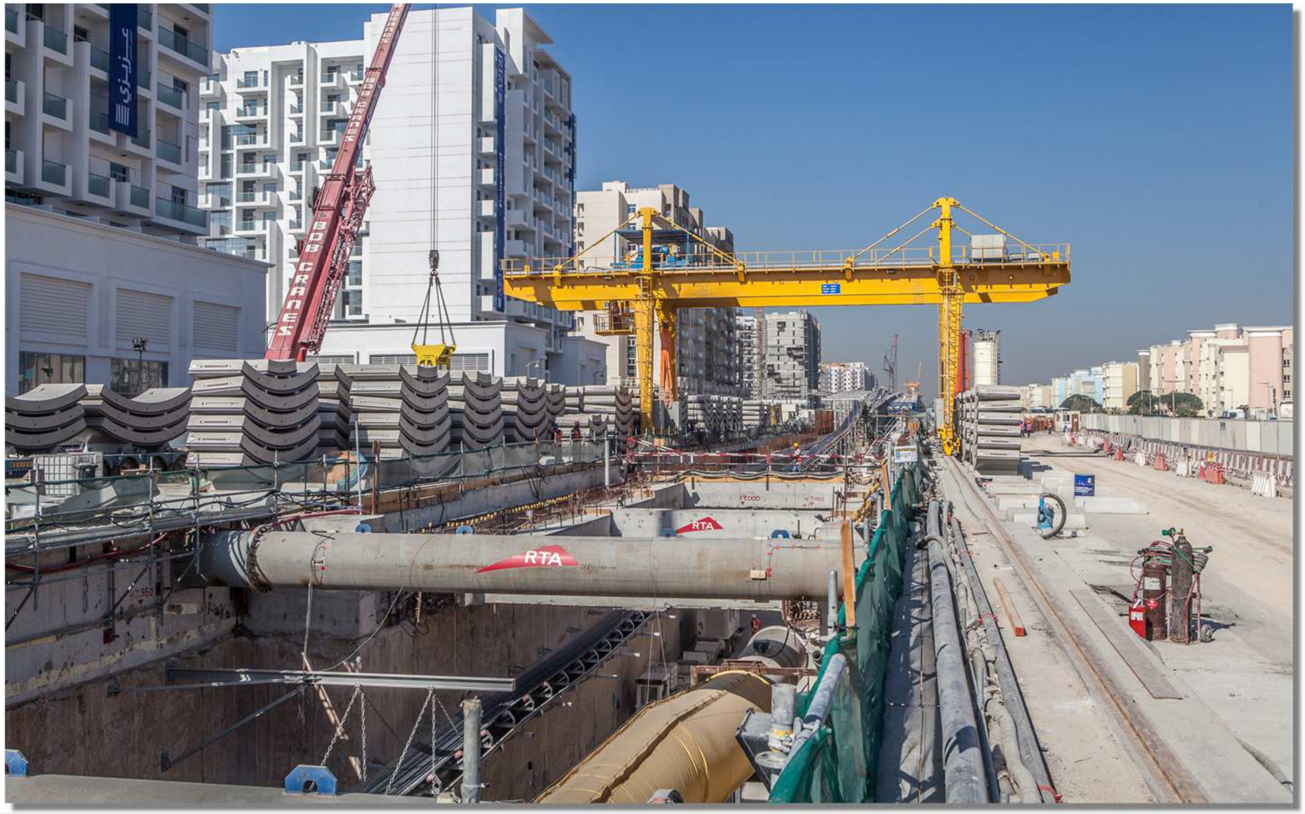
Risks:

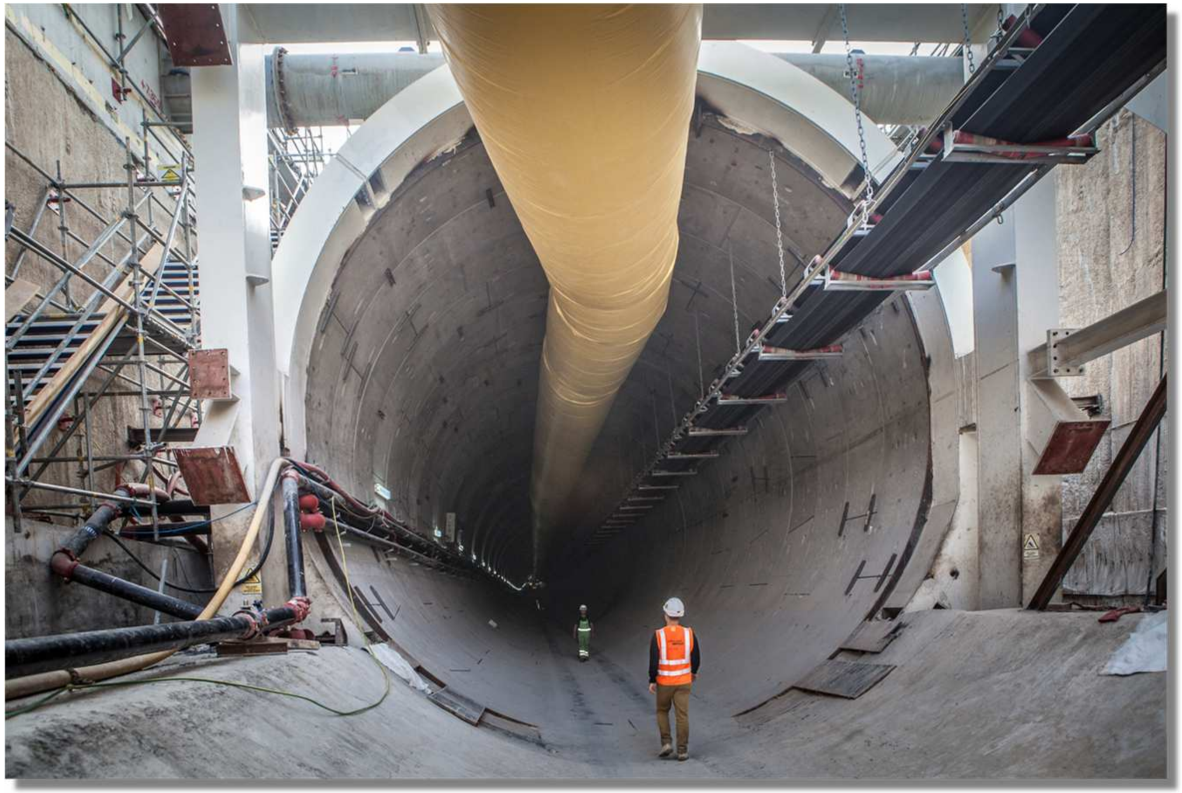
- Water mains running close to tunnel crown (require diversion)
- Increased geotechnical/tunnelling risk due to shallow cover
- Increase duration of TBM tunnelling works due to additional length of 391m to replace the cut and cover length present in the original design.



- **<u>Mitigation measure (Structural and Geotechnical design)</u>**
- Soil Improvement
- Construction of an inclined structural concrete slab to remain as a permanent structure
- Diaphragm walls
- Geotechnical protection works -concrete slab- temporary works for protection purposes only


11kV Lines
TUNNEL
Concrete Slab
LPG/Gas Line
11kV Lines
Water Mains
Concrete Reinforced Retaining Structure
Inclined Concrete Slab
D-Wall
D-Wall


BOB CRANES
RTA
RTA



- The additional 391m of tunnel drive require additional 1.5 months on the TBM Tunnel construction schedule.
- TBM construction program, improved by 1.5 months.

TBM productivity achieved as planned:

- First 353m @ 7.4m/day = 48 Days
- Next 646m @ 11.5m/day = 56 Days
- Next 709m @ 12.9m/day = 55 Days
- Last 680m @ 12.6m/day = 54 Days

- **CONCLUSIONS:**

- The rigorous risk management approach that was implemented led to a successful completion of the shallow TBM launch alternative on R2020 project.

- Structural and qualitative mitigation measures were designed and implemented in order to ensure a fully controlled construction environment.

- All decisions were carried out in a highly collaborative manner between the Client, the Contractor and the Designer. All parties were mindful of the drivers of each other and everybody in the management team had a similar understanding of the risks.

- This success demonstrates that with a collaborative work model, innovative solutions can be applied and executed in a structured and safe manner that can lead to benefits for the Client and the Contractor alike.

3.2. TBM Tunneling under buildings in bad geological conditions

(Gijón, Spain)

METRO TREN (GIJON,SPAIN (2003))

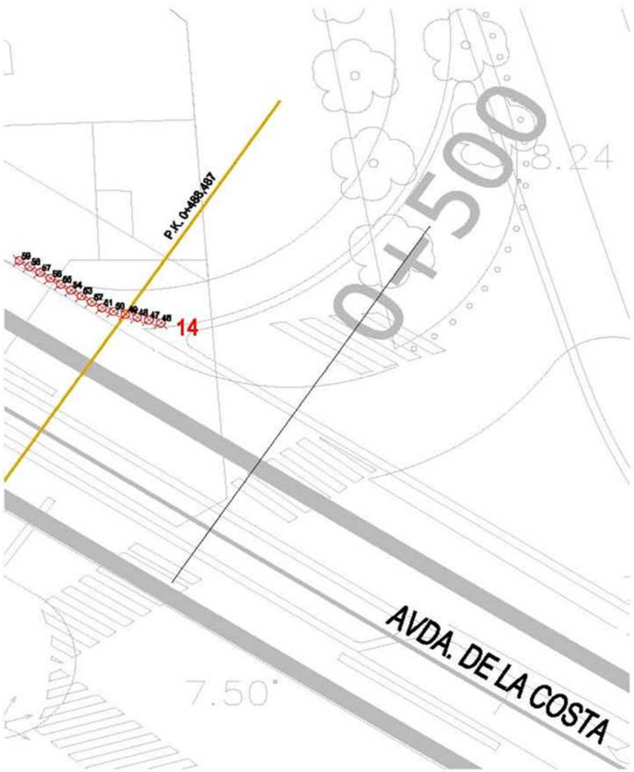
CONTRACTOR: ACCIONA

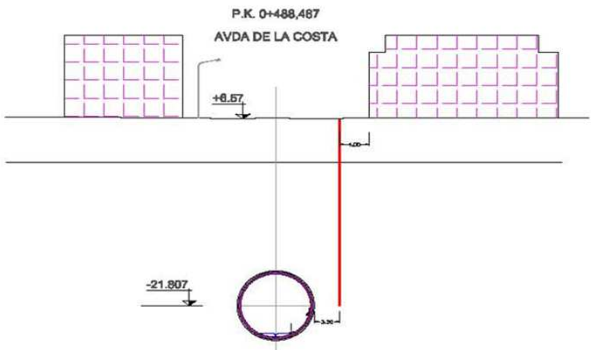
CLIENT: Ministry of Public Works and Transport (Spanish Government)

CONTRACT VALUE: 1.4 B NOK

SCOPE: 3,9 Km of single tunnel (EPB D=10.55m) 2 stations

- Main alignment of the tunnel under streets, avoiding buildings
- Some mitigation measures for settlement in buildings (steel micropiles from surface)
- Change in design in order to minimize Tunneling under buildings
- Callenge in an specific area.



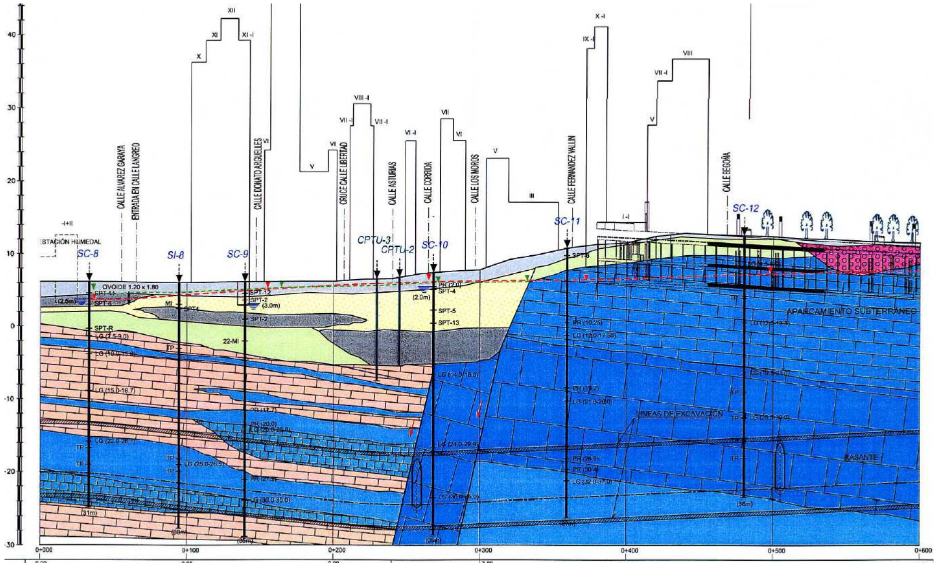


Geological profile:

- Main TBM excavation in marls and dolomitized limestone, with some clay inclusions. Water level at surface.

- Due to change in alignment, some buildings on the top of tunnel with presence of silt, potential settlements.

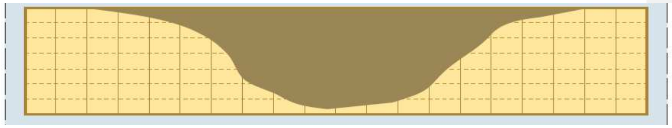
- It required specific design and treatment: **Soilfrac compensation grouting**. Soilfrac® is a process used to control or reverse the settlement of structures. It consists of the injection of material into the soil between the foundation to be controlled and the tunnel that can cause the settlement.

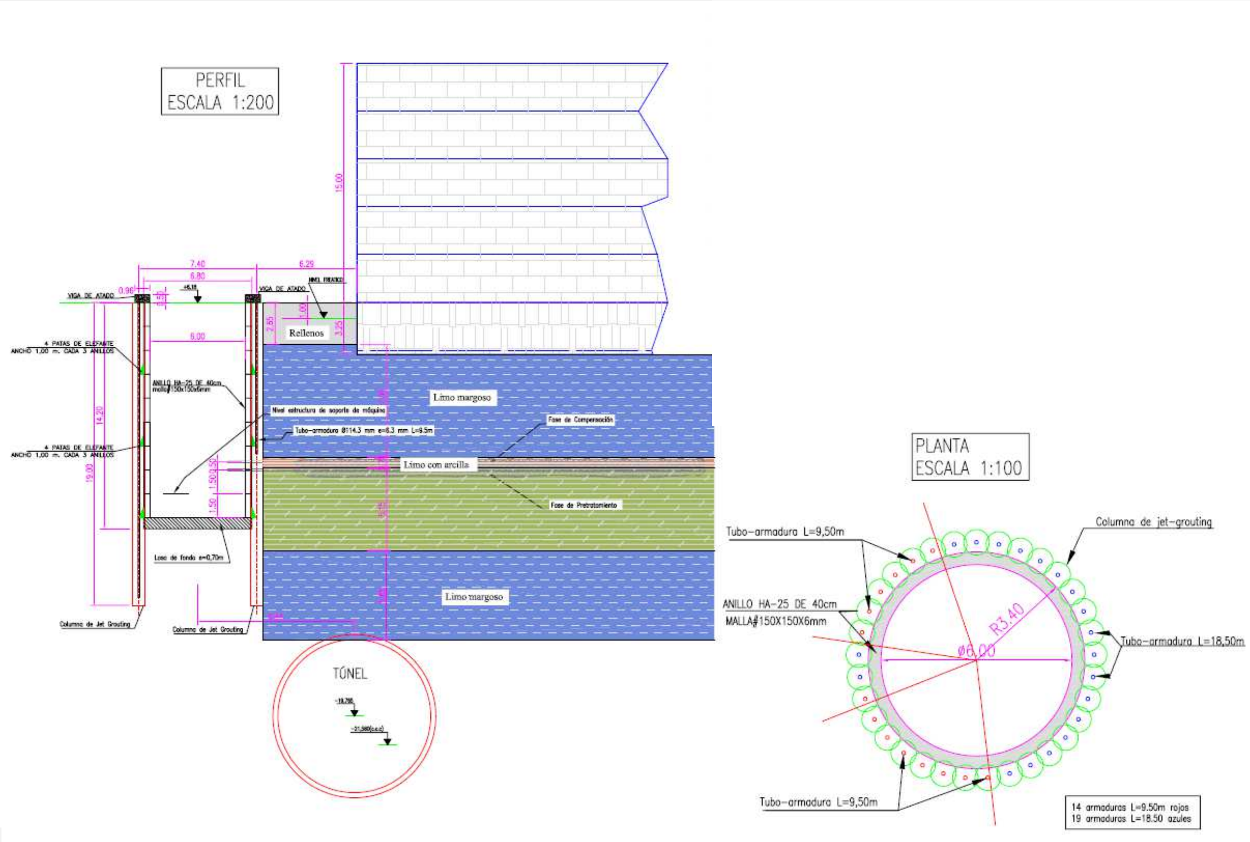


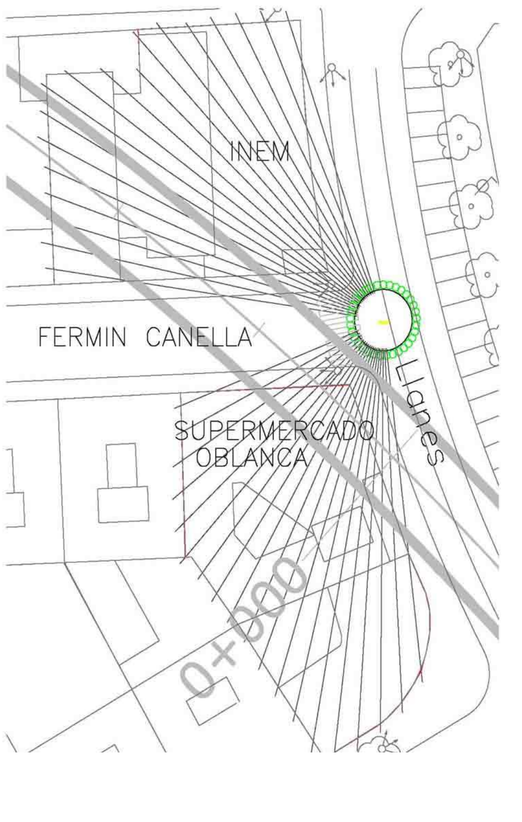
Soilfrac compensation grouting:

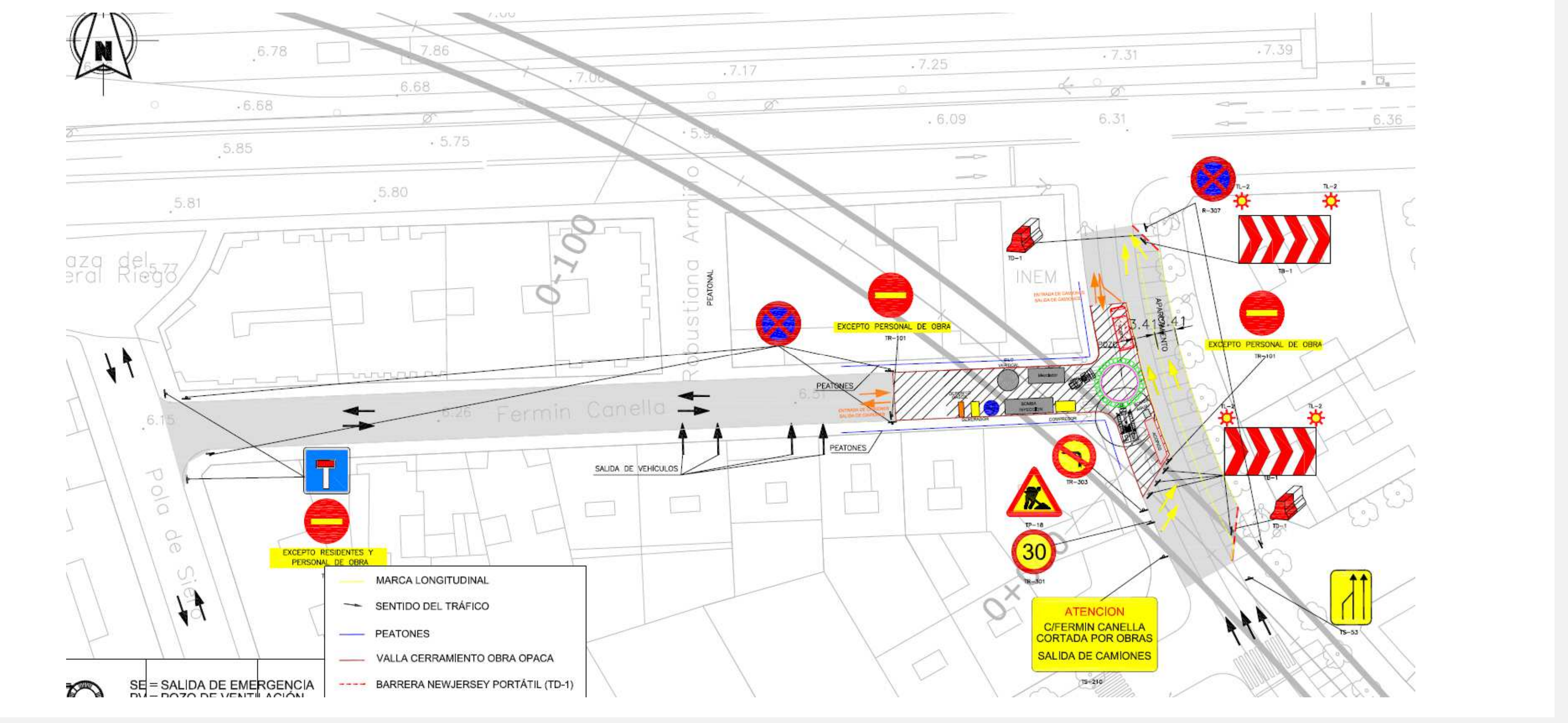
A. Evaluate and quantify potential settlements
B. Before the tunnel is executed, the material is previously injected into fractures, thereby causing an expansion (vertical movement in affected buildings have to be controlled under very sensitive electronic survey).
C. Tunnel excavation occurs and provisional settlement takes place.
D. Simultaneous compensation grouting is executed, counteracting the settlement that occurs or producing a controlled heave of the foundation.
E. Final assumable settlement

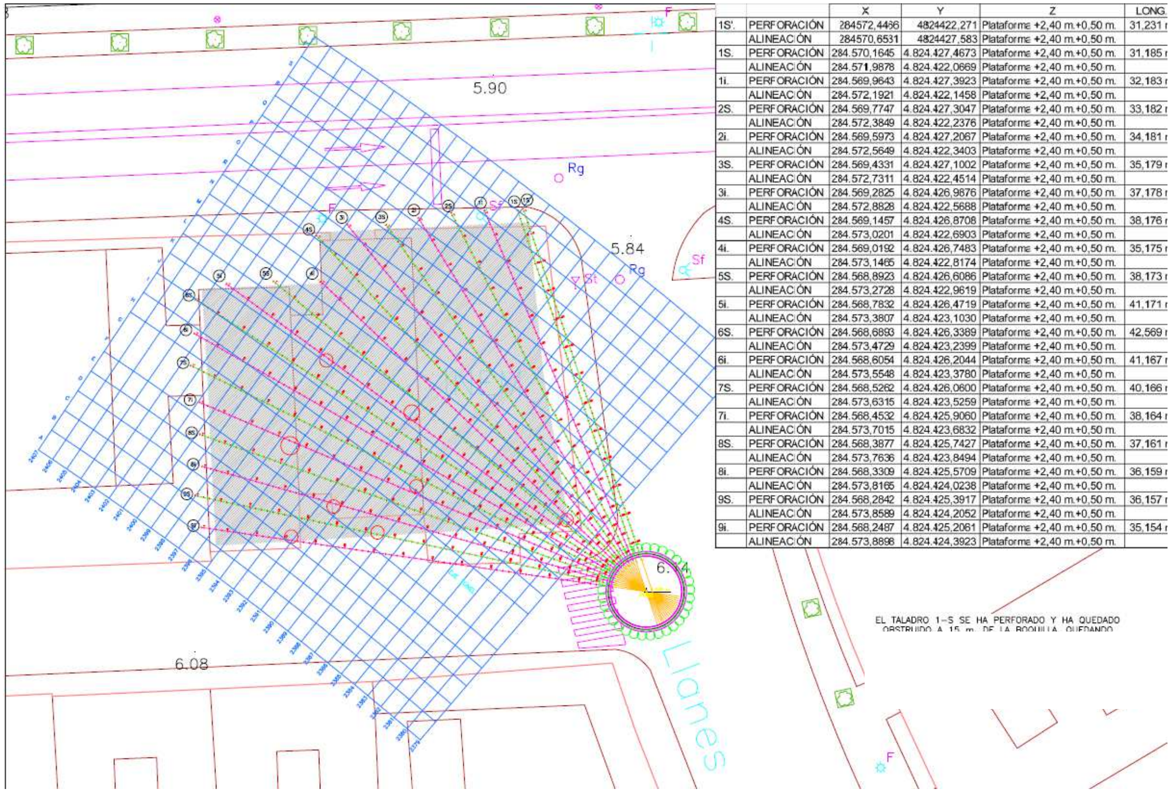
A




PERFIL
ESCALA 1:200
Rellenos
Limo margoso
Limo con arcilla
Limo margoso
TÚNEL
PLANTA
ESCALA 1:100
Tubo-armadura L=9,50m
Columna de jet-grouting
ANILLO HA-25 DE 40cm
MALLA Ø150X150X6mm
R3.40
Ø6.00
Tubo-armadura L=18,50m
Tubo-armadura L=9,50m
14 armaduras L=9.50m rojos
19 armaduras L=18.50 azules


INEM
FERMIN CANELLA
SUPERMERCADO
OBLANCA
Llanes
0+000


Fermin Canella
Pola de Siero
INEM
EXCEPTO PERSONAL DE OBRA
EXCEPTO RESIDENTES Y PERSONAL DE OBRA
PEATONES
SALIDA DE VEHICULOS
ATENCION
C/FERMIN CANELLA CORTADA POR OBRAS
SALIDA DE CAMIONES
30
MARCA LONGITUDINAL
SENTIDO DEL TRÁFICO
PEATONES
VALLA CERRAMIENTO OBRA OPACA
BARRERA NEWJERSEY PORTÁTIL (TD-1)
SE = SALIDA DE EMERGENCIA



		X	Y	Z	LONG.
1S'.	PERFORACIÓN	284572,4466	4824422,271	Plataforma +2,40 m.+0,50 m.	31,231
	ALINEACIÓN	284570,6531	4824427,583	Plataforma +2,40 m.+0,50 m.	
1S.	PERFORACIÓN	284.570,1645	4.824.427,4673	Plataforma +2,40 m.+0,50 m.	31,185
	ALINEACIÓN	284.571,9878	4.824.422,0669	Plataforma +2,40 m.+0,50 m.	
1i.	PERFORACIÓN	284.569,9643	4.824.427,3923	Plataforma +2,40 m.+0,50 m.	32,183
	ALINEACIÓN	284.572,1921	4.824.422,1458	Plataforma +2,40 m.+0,50 m.	
2S.	PERFORACIÓN	284.569,7747	4.824.427,3047	Plataforma +2,40 m.+0,50 m.	33,182
	ALINEACIÓN	284.572,3849	4.824.422,2376	Plataforma +2,40 m.+0,50 m.	
2i.	PERFORACIÓN	284.569,5973	4.824.427,2067	Plataforma +2,40 m.+0,50 m.	34,181
	ALINEACIÓN	284.572,5649	4.824.422,3403	Plataforma +2,40 m.+0,50 m.	
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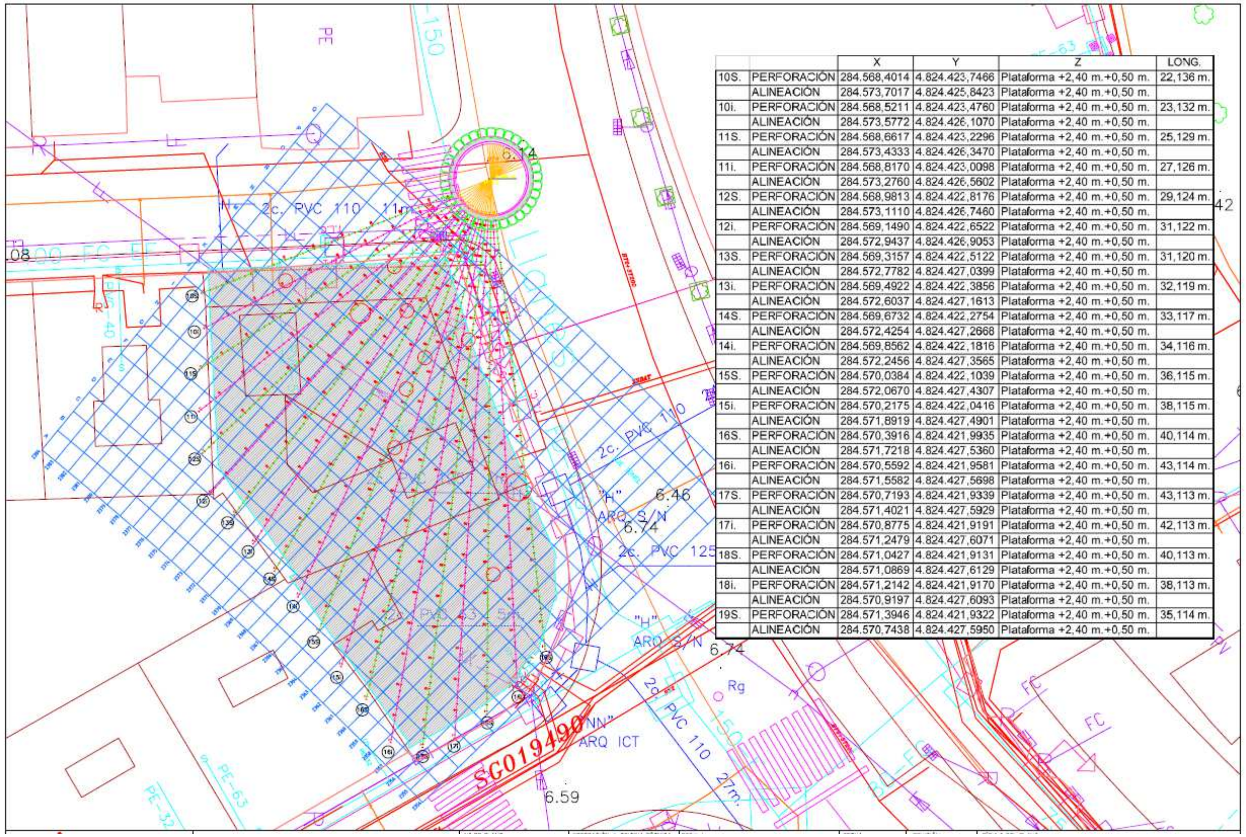
	ALINEACIÓN	284.572,7311	4.824.422,4514	Plataforma +2,40 m.+0,50 m.	
3i.	PERFORACIÓN	284.569,2825	4.824.426,9876	Plataforma +2,40 m.+0,50 m.	37,178
	ALINEACIÓN	284.572,8828	4.824.422,5688	Plataforma +2,40 m.+0,50 m.	
4S.	PERFORACIÓN	284.569,1457	4.824.426,8708	Plataforma +2,40 m.+0,50 m.	38,176
	ALINEACIÓN	284.573,0201	4.824.422,6903	Plataforma +2,40 m.+0,50 m.	
4i.	PERFORACIÓN	284.569,0192	4.824.426,7483	Plataforma +2,40 m.+0,50 m.	35,175
	ALINEACIÓN	284.573,1465	4.824.422,8174	Plataforma +2,40 m.+0,50 m.	
5S.	PERFORACIÓN	284.568,8923	4.824.426,6086	Plataforma +2,40 m.+0,50 m.	38,173
	ALINEACIÓN	284.573,2728	4.824.422,9619	Plataforma +2,40 m.+0,50 m.	
5i.	PERFORACIÓN	284.568,7832	4.824.426,4719	Plataforma +2,40 m.+0,50 m.	41,171
	ALINEACIÓN	284.573,3807	4.824.423,1030	Plataforma +2,40 m.+0,50 m.	
6S.	PERFORACIÓN	284.568,6893	4.824.426,3389	Plataforma +2,40 m.+0,50 m.	42,569
	ALINEACIÓN	284.573,4729	4.824.423,2399	Plataforma +2,40 m.+0,50 m.	
6i.	PERFORACIÓN	284.568,6054	4.824.426,2044	Plataforma +2,40 m.+0,50 m.	41,167
	ALINEACIÓN	284.573,5548	4.824.423,3780	Plataforma +2,40 m.+0,50 m.	
7S.	PERFORACIÓN	284.568,5262	4.824.426,0600	Plataforma +2,40 m.+0,50 m.	40,166
	ALINEACIÓN	284.573,6315	4.824.423,5259	Plataforma +2,40 m.+0,50 m.	
7i.	PERFORACIÓN	284.568,4532	4.824.425,9060	Plataforma +2,40 m.+0,50 m.	38,164
	ALINEACIÓN	284.573,7015	4.824.423,6832	Plataforma +2,40 m.+0,50 m.	
8S.	PERFORACIÓN	284.568,3877	4.824.425,7427	Plataforma +2,40 m.+0,50 m.	37,161
	ALINEACIÓN	284.573,7636	4.824.423,8494	Plataforma +2,40 m.+0,50 m.	
8i.	PERFORACIÓN	284.568,3309	4.824.425,5709	Plataforma +2,40 m.+0,50 m.	36,159
	ALINEACIÓN	284.573,8165	4.824.424,0238	Plataforma +2,40 m.+0,50 m.	
9S.	PERFORACIÓN	284.568,2842	4.824.425,3917	Plataforma +2,40 m.+0,50 m.	36,157
	ALINEACIÓN	284.573,8589	4.824.424,2052	Plataforma +2,40 m.+0,50 m.	
9i.	PERFORACIÓN	284.568,2487	4.824.425,2061	Plataforma +2,40 m.+0,50 m.	35,154
	ALINEACIÓN	284.573,8898	4.824.424,3923	Plataforma +2,40 m.+0,50 m.	



		X	Y	Z	LONG.
10S.	PERFORACIÓN	284.568,4014	4.824.423,7466	Plataforma +2,40 m.+0,50 m.	22,136 m.
	ALINEACIÓN	284.573,7017	4.824.425,8423	Plataforma +2,40 m.+0,50 m.	
10i.	PERFORACIÓN	284.568,5211	4.824.423,4760	Plataforma +2,40 m.+0,50 m.	23,132 m.
	ALINEACIÓN	284.573,5772	4.824.426,1070	Plataforma +2,40 m.+0,50 m.	
11S.	PERFORACIÓN	284.568,6617	4.824.423,2296	Plataforma +2,40 m.+0,50 m.	25,129 m.
	ALINEACIÓN	284.573,4333	4.824.426,3470	Plataforma +2,40 m.+0,50 m.	
11i.	PERFORACIÓN	284.568,8170	4.824.423,0098	Plataforma +2,40 m.+0,50 m.	27,126 m.
	ALINEACIÓN	284.573,2760	4.824.426,5602	Plataforma +2,40 m.+0,50 m.	
12S.	PERFORACIÓN	284.568,9813	4.824.422,8176	Plataforma +2,40 m.+0,50 m.	29,124 m.
	ALINEACIÓN	284.573,1110	4.824.426,7460	Plataforma +2,40 m.+0,50 m.	
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	ALINEACIÓN	284.572,9437	4.824.426,9053	Plataforma +2,40 m.+0,50 m.	
13S.	PERFORACIÓN	284.569,3157	4.824.422,5122	Plataforma +2,40 m.+0,50 m.	31,120 m.
	ALINEACIÓN	284.572,7782	4.824.427,0399	Plataforma +2,40 m.+0,50 m.	
13i.	PERFORACIÓN	284.569,4922	4.824.422,3856	Plataforma +2,40 m.+0,50 m.	32,119 m.
	ALINEACIÓN	284.572,6037	4.824.427,1613	Plataforma +2,40 m.+0,50 m.	
14S.	PERFORACIÓN	284.569,6732	4.824.422,2754	Plataforma +2,40 m.+0,50 m.	33,117 m.
	ALINEACIÓN	284.572,4254	4.824.427,2668	Plataforma +2,40 m.+0,50 m.	
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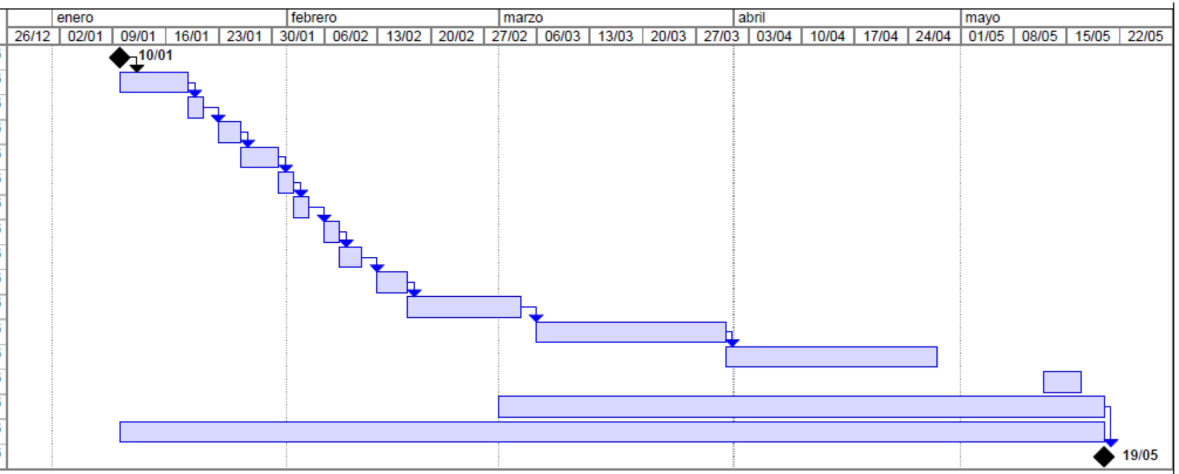
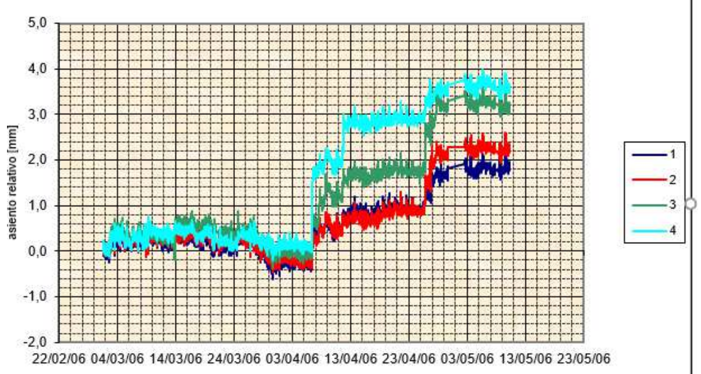
	ALINEACIÓN	284.572,0670	4.824.427,4307	Plataforma +2,40 m.+0,50 m.	
15i.	PERFORACIÓN	284.570,2175	4.824.422,0416	Plataforma +2,40 m.+0,50 m.	38,115 m.
	ALINEACIÓN	284.571,8919	4.824.427,4901	Plataforma +2,40 m.+0,50 m.	
16S.	PERFORACIÓN	284.570,3916	4.824.421,9935	Plataforma +2,40 m.+0,50 m.	40,114 m.
	ALINEACIÓN	284.571,7218	4.824.427,5360	Plataforma +2,40 m.+0,50 m.	
16i.	PERFORACIÓN	284.570,5592	4.824.421,9581	Plataforma +2,40 m.+0,50 m.	43,114 m.
	ALINEACIÓN	284.571,5582	4.824.427,5698	Plataforma +2,40 m.+0,50 m.	
17S.	PERFORACIÓN	284.570,7193	4.824.421,9339	Plataforma +2,40 m.+0,50 m.	43,113 m.
	ALINEACIÓN	284.571,4021	4.824.427,5929	Plataforma +2,40 m.+0,50 m.	
17i.	PERFORACIÓN	284.570,8775	4.824.421,9191	Plataforma +2,40 m.+0,50 m.	42,113 m.
	ALINEACIÓN	284.571,2479	4.824.427,6071	Plataforma +2,40 m.+0,50 m.	
18S.	PERFORACIÓN	284.571,0427	4.824.421,9131	Plataforma +2,40 m.+0,50 m.	40,113 m.
	ALINEACIÓN	284.571,0869	4.824.427,6129	Plataforma +2,40 m.+0,50 m.	
18i.	PERFORACIÓN	284.571,2142	4.824.421,9170	Plataforma +2,40 m.+0,50 m.	38,113 m.
	ALINEACIÓN	284.570,9197	4.824.427,6093	Plataforma +2,40 m.+0,50 m.	
19S.	PERFORACIÓN	284.571,3946	4.824.421,9322	Plataforma +2,40 m.+0,50 m.	35,114 m.
	ALINEACIÓN	284.570,7438	4.824.427,5950	Plataforma +2,40 m.+0,50 m.	

Id		Nombre de tarea	Duración	Comienzo
1		INICIO	0 días	mar 10/01/06
2		Anillo 1	7 días	mar 10/01/06
3		Anillo 2	2 días	jue 19/01/06
4		Anillo 3	3 días	lun 23/01/06
5		Anillo 4	3 días	jue 26/01/06
6		Anillo 5	2 días	mar 31/01/06
7		Anillo 6	2 días	jue 02/02/06
8		Anillo 7	2 días	lun 06/02/06
9		Anillo 8	3 días	mié 08/02/06
10		Anillo 9	4 días	lun 13/02/06
11		Estructura de apoyo	11 días	vie 17/02/06
12		Perforación inyecciones	19 días	lun 06/03/06
13		Inyección previa	20 días	vie 31/03/06
14		Inyección compensación	3 días	vie 12/05/06
15		Auscultación hidroniveles	58 días	mié 01/03/06
16		Seguridad y Salud	94 días?	mar 10/01/06
17		FIN	0 días	vie 19/05/06




ROVER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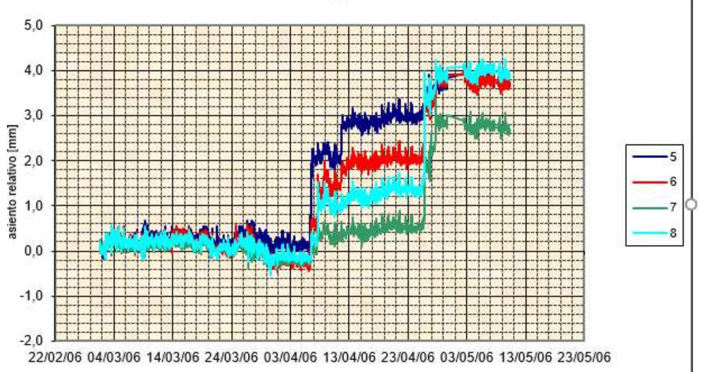
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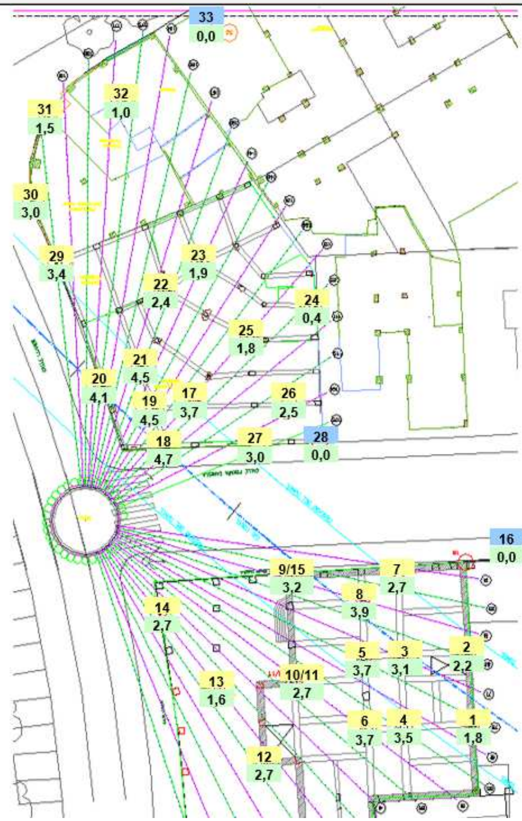
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17 3,7
26 2,5
18 4,7
27 3,0
28 0,0
16 0,0
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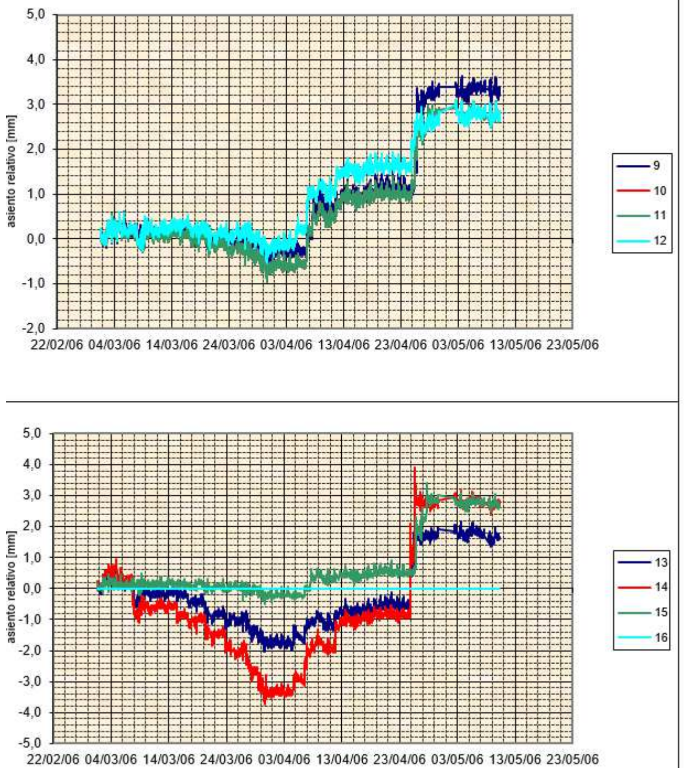

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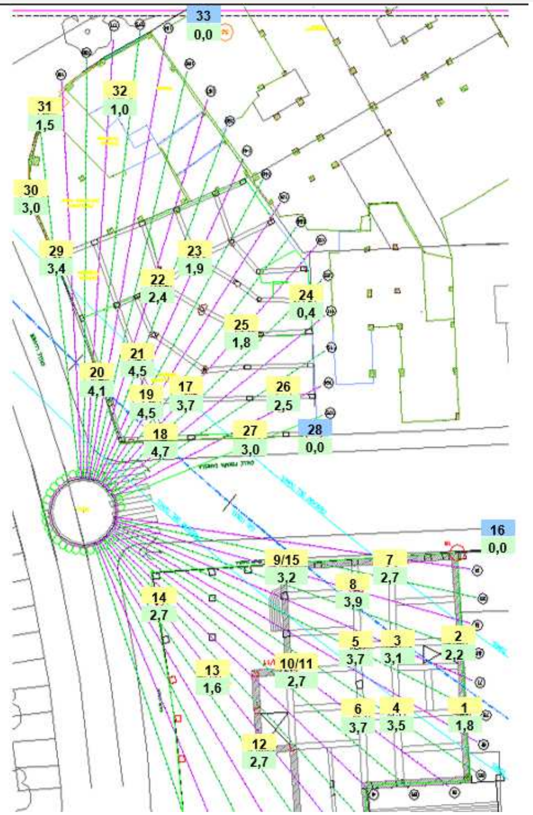

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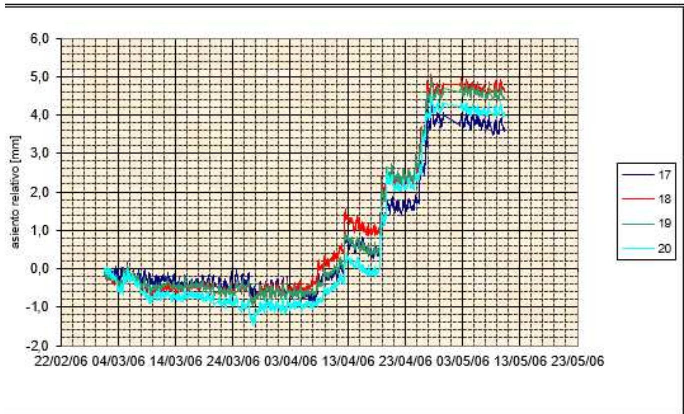
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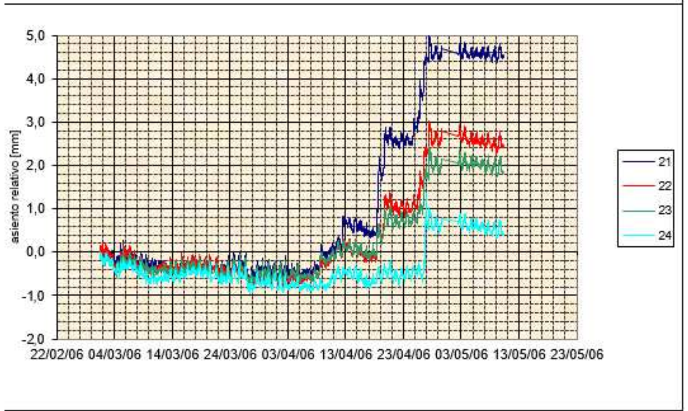
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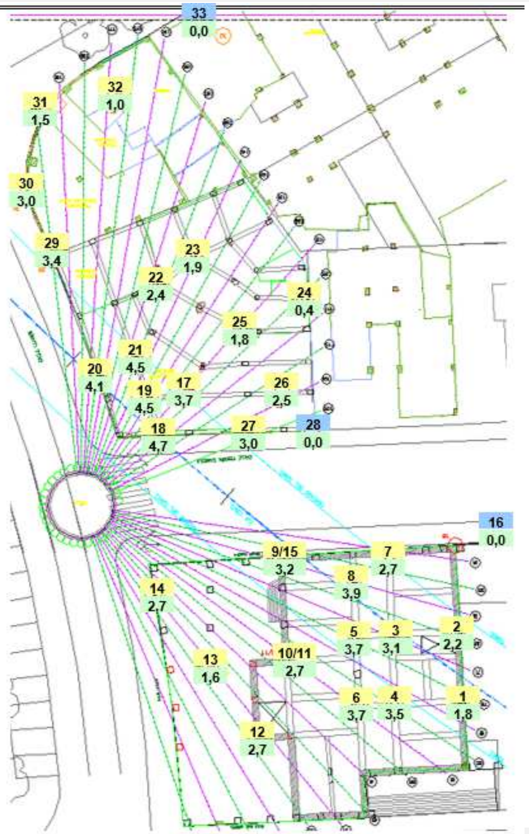
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- **FINAL CONCLUSIONS:**
- TBM Urban tunnels are coming...
- TBM providers market is mature for any complex tunnels request.
- Open for innovation. EASY TUNNELS ARE ALREADY BUILT!
- Client, Contractor and Designer have to be one team and have a similar understanding of the risks.
- Cannot only be Contractors problem. Changes and innovations normally becomes a win - win situation.

acciona

Thank you for your attention