The Spanish experience in large tunnels

A new urban solution
NEW TECHNOLOGIES

- Safer
- Environmental friendly
- Minimize citizen disturbances
- Reducing cost and schedules
MADRID “CALLE 30”

3,7 billion euros project
“CALLE 30” Targets

• Move to underground the greatest portion of the road and links. Green areas replace the congested surface
• Increase and improve the traffic flow
• Increase the traffic safety
• Redesign the 6 main links with National roads
MADRID “CALLE 30”
MADRID "CALLE 30"
“CALLE 30” Targets

• Save 14.000.000 hours in journeys every year
• Save 4,5 Million € in fuel yearly
• Reduce 35.000 ton yearly in CO2 emissions
• Reduce 400 car accidents every year
MADRID “CALLE 30”

CONSTRUCTION OPTIONS:

• CUT & COVER

• ELEVATED ROAD

• BORE TUNNEL
MADRID “CALLE 30”

SOUTH BY PASS
SOUTH TUNNEL

Contract price: 410 million € (VAT incl.)

Contract schedule: 30 month
MADRID CALLE 30

CROSS SECTION
- 3 lanes 3.5 m for heavy and light vehicles
- Emergency gallery
- Ventilation and facilities

1 VENTILATION SHAFT

CROSS PASSAGES (every 300 m)
- 3 Vehicle galleries
- 5 Pedestrian galleries
FINAL CROSS SECTION
MADRID CALLE 30

- Tunnel length: 2.24 miles
- Excavation diameter: 49.25 feet
- Excavation volume: 831,856 cy
- Inner diameter: 44.13 feet
- Segments thickness: 1.97 feet
- Segments length: 6.56 feet
• Ground conditions:
  – Deposit materials from 0 to 66 feet
  – 80 to 100 feet of sandy clay (Peñuela)
  – 66 to 80 feet of hard clay with Gypsum levels
• Maximum overburden 213 feet
• Average overburden 100 – 115 feet
MADRID “CALLE 30”

PRELIMINARY DESIGN
The first stretch of the Madrid Metro (2.5 miles) was opened in 1919.

Extension 1995 - 1999
- 35 New miles in 2 track tunnels, 37 Stations and 4 interchange
- Length of the network after extension: 109 miles

Extension 1999 – 2003
- 34 miles
- 39 stations

Extension 2003 – 2007
- 49 miles
- 80 stations

Current length in 2009 is 193 miles (310 km)
Earth Pressure Balance (E.P.B.)

First EPB in Madrid (1993) (Railway administration)
Single track tunnel (24.2 feet)

TBM 30.8 feet diameter
Double track tunnel
Metro Madrid
THRUST REQUIREMENTS

• Avoid horizontal deformation in the front face
• Balance the ground effective horizontal pressure
• Balance the water pressure on the ground
• Avoid the vertical settlement on surface in front of the excavation
• Shield friction during the excavation
THRUST REQUIREMENTS

CROSS SECTIONS COMPARAISON

1-2,5

• THRUST TBM METRO 10,000 TON

• THRUST TBM “CALLE 30” 25,000 TON
TBM comparison

Diameter (m)

Máx. Thrust (Ton.)
TORQUE REQUIREMENTS

• Dig the ground with cutter tools (pics)
• Friction between ground and cutterhead
• Radial and tangential forces applied in the main bearing
• Friction on sealing lips
• Mix the soils inside the chamber
TORQUE REQUIREMENTS

VOLUME COMPARAISON

• TORQUE TBM METRO 2.000 TON x M

• TORQUE TBM “CALLE 30” 8.240 TON x M
TBM comparison

Diameter (m)

Máx. Torque (kNm)

M - 30 2004

Madrid Metro extension 1995-1999
GERMAN CONCEPT
HERRENKNECHT DESIGN

DOUBLE CUTTERHEAD
HERRENKNECHT DESIGN

INVERSE

ROTATION
JAPANESE CONCEPT
MITSUBISHI DESIGN

SINGLE CUTTERHEAD

UCA Seattle
MITSUBISHI DESIGN

1 SCREW CONVEYOR

1 CENTER AGITATOR

2 SEGMENT ERECTORS
SEGMENT ERECTION
# MADRID “CALLE 30”

<table>
<thead>
<tr>
<th>Model</th>
<th>MHI -DF</th>
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<tbody>
<tr>
<td>Diameter</td>
<td>15,010 m</td>
</tr>
<tr>
<td>Length TBM</td>
<td>13,075 m</td>
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<tr>
<td>Weight TBM</td>
<td>2,700 T</td>
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<tr>
<td>Length Back-up</td>
<td>150 m</td>
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<tr>
<td>Minimum horizontal radius</td>
<td>350 m</td>
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<tr>
<td>Maximum working pressure in chamber</td>
<td>6 bar</td>
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<tr>
<td>Maximum Thrust</td>
<td>317,000 kN</td>
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<tr>
<td>Cutterhead power</td>
<td>9,800 Kw.</td>
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<tr>
<td>Maximum torque at 1,05 r.p.m.</td>
<td>85,700 kNm</td>
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<tr>
<td>Rotation speed</td>
<td>0.1 / 2.43 r.p.m.</td>
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### MADRID “CALLE 30”

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Number of drag bits</td>
<td>472</td>
</tr>
<tr>
<td>Number of knife edge bits</td>
<td>226</td>
</tr>
<tr>
<td>Number of disc cutters (triple)</td>
<td>44</td>
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<tr>
<td>Number of trim bits</td>
<td>32</td>
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<tr>
<td>Number of thrust cylinders</td>
<td>57</td>
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<tr>
<td>Central agitator diameter</td>
<td>5 m</td>
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<tr>
<td>Screw conveyor diameter</td>
<td>1.5 m</td>
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<tr>
<td>Total Power installed</td>
<td>14,300 kW</td>
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MADRID “CALLE 30”

This is a guy!!!
MADRID "CALLE 30"
Monitoring and Technical Control Unit
MTCU

• Building characterization study
• Monitoring plan
• Installation of the instrumentation
• Instrumentation reading frequency
• Data interpretation and report generation
Integrated Monitoring System
IMS

- **Instrumentation Unit**: Centralizes, stores and shows all the readings taken from the installed devices. It shows the state of the sensors in comparison with the adopted alarm thresholds.

- **Building Unit**: Centralizes, stores and shows all the information related to each inspected building. It also shows the registered movements by the instrumentation installed in them.

- **Execution Unit**: Allows visualizing, consulting and monitoring the job advance degree in its different areas.

- **Documentary Unit**: Centralizes, stores and shows the job most interesting information.
LAUNCHING SHAFT
LAUNCHING SHAFT
300 x 150 feet
CONTROLS DURING EXCAVATION

> Front face support pressure

> Mortar injection pressure and volume

> Cumulative weight and volume of extracted material from cutterhead chamber

> Ground conditioning agents

> Particular events to be controlled during excavation (Cutterhead blockage, Gas, Water seepage...)

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PROGRESS RATES
PRODUCTION

(Meters)

3500
4000

Av: 60 feet/day

CALLE 30
SOUTH BY-PASS
SOUTH TUNNEL

9 Oct 06: 151 feet

Oct 06: 865 yards

22/9-21/10: 1,015 yards
BREAKTHROUGH SOUTH TUNNEL
INTERMEDIATE SLAB
Cantilever formwork
Precast slab installation following the TBM progress
CROSS PASSAGES
MADRID Method
MADRID Method
MADRID Method
MADRID Method
LESSONS LEARNED

>TBM CURRENT TECHNOLOGY ALLOWS LARGE BORE TUNNEL DESIGNS

>PROPER TBM DESIGN IN ACCORDANCE WITH GROUND CONDITIONS IS THE KEY ISSUE FOR SUCCESS

>EXPERIENCED TEAMS ARE HIGHLY RECOMMENDED

>INTENSE SUPERVISION AND MONITORING TOGETHER WITH IMMEDIATE REMEDIAL PROCEDURES REDUCE DISCOMFORT TO THE NEIGHBORHOOD (MTCU)

>CLOSE RELATIONSHIP WITH THE CLIENT AND DESIGNERS ALLOWS TO RESOLVE THE PROBLEMS EVEN BEFORE THEY OCCURS
TO BE CONSIDERED IN PRELIMINARY DESIGNS

> VENTILATION
> FLOODING
> FIRE
> EVACUATION ROUTES
BARCELONA
METRO
LINE 9
GEOLGY

- Paleozoic and Tertiary formations covered by Pleistocene and Quaternary materials
- Miocene. Gravel with clay matrix
- In Delta rivers, pliocene alluviums
CONTINUOUS STATION
CONCEPTUAL DESIGN
LINE 9

- Reduce surface disturbance
- Less subsidence in deep tunnel (2 D cover)
- Station platforms inside the tunnel
- Crossing other underground facilities
- Four track capacity
2 X E.P.B. 39’ 5” diameter
SEGMENT RING

- Inner diameter…….35.8 feet
- Thickness………………1.3 feet
- Length……………….5.9 feet
- Bolted and center bars between segments
- Bolted and connectors between rings
INTERMEDIATE SLAB

UCA Seattle

May 09
SLAB IN STATIONS
NEW TECHNOLOGIES

- See through ground
- Environmental friendly ground treatments
- Sophisticated TBM’s
- Monitoring on-line
- Muck materials recycling
- Fire resistant lining materials
- Arrangement of underground space
OTHERS PROPOSALS
UNDERGROUND SPACE

SOCIAL BENEFITS

• New open mind of the citizens related to the underground space
• Create more green areas at grade removing existing infrastructures
• Increase the transportation network and reduce the journies
• Increase the companies competivity
• Nouxious gases reduction
• Noise reduction