

Metrosur

First Edition

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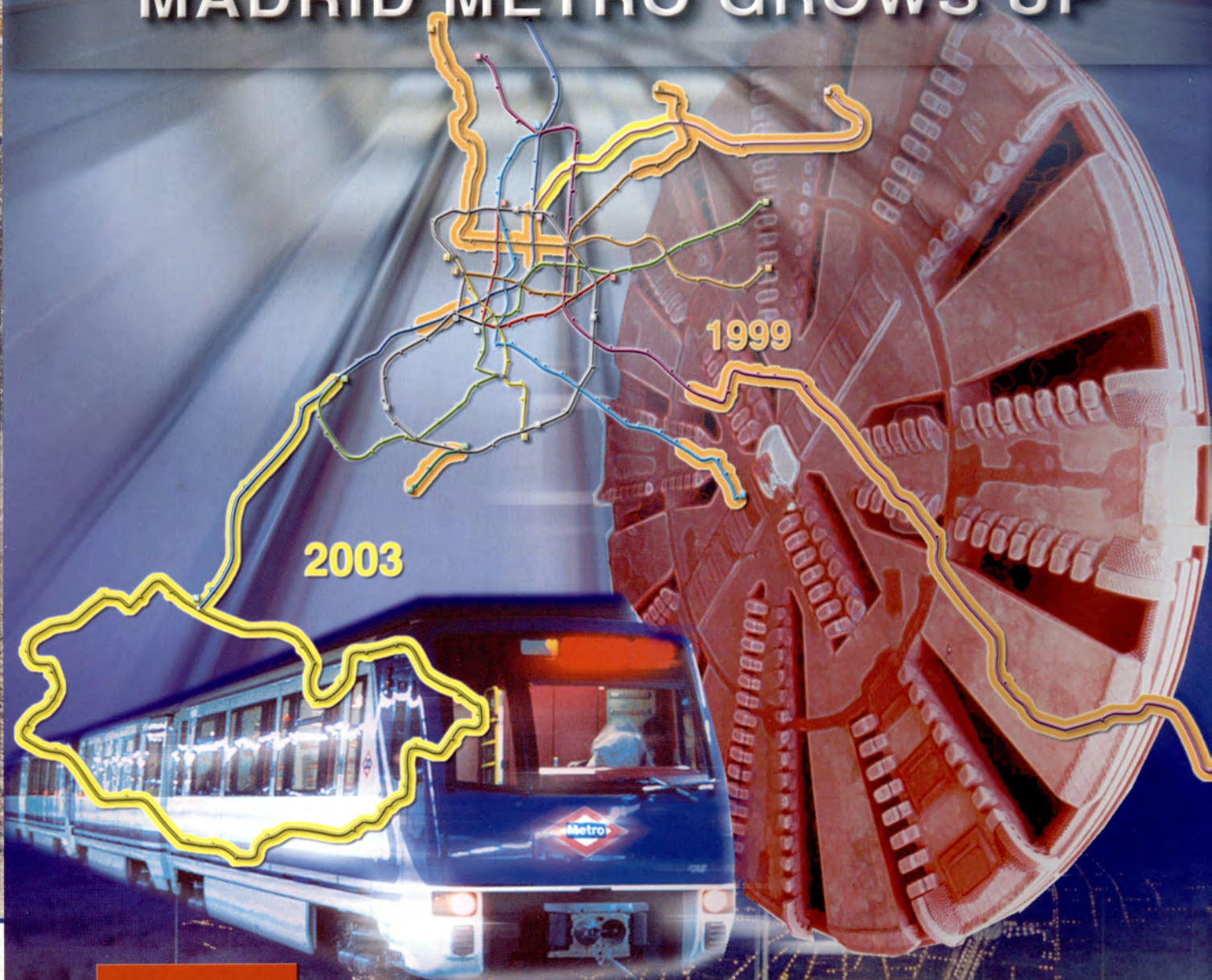
Commuting in the 21st Century

a tunnelbuilder reference edition

1995 - 1999
56.31 km in 40 months

1999 - 2003
54.70 km now building
in 40 months

MADRID METRO GROWS UP

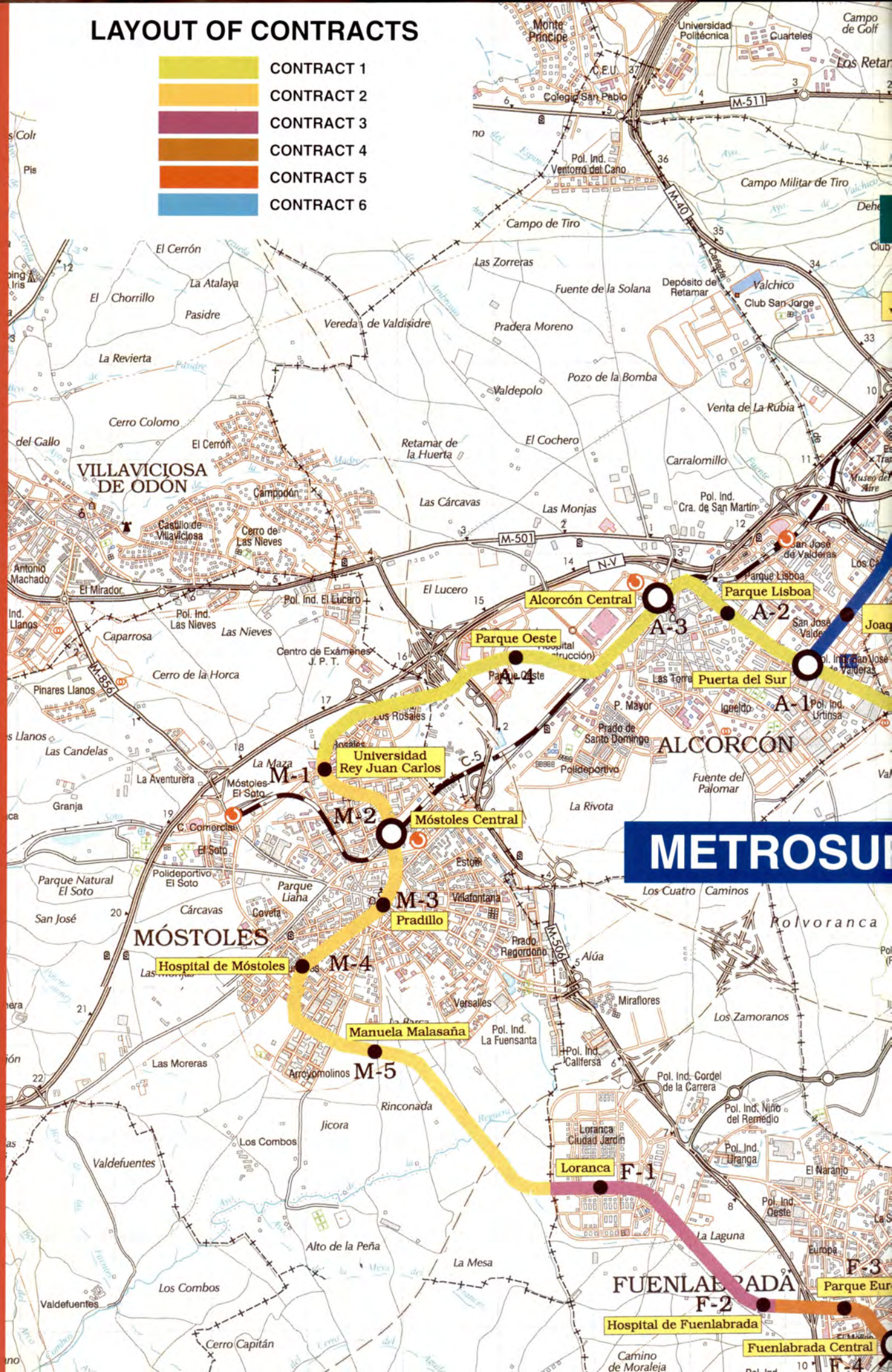


**CONSEJERIA DE OBRAS PUBLICAS
URBANISMO Y TRANSPORTES**

Comunidad de Madrid

LAYOUT OF CONTRACTS

- CONTRACT 1
- CONTRACT 2
- CONTRACT 3
- CONTRACT 4
- CONTRACT 5
- CONTRACT 6





LINE 10

San Nicasio

LEGANÉS

Leganés Central

Julián Besteiro

Casa del Reloj

Hospital Severo Ochoa

El Carrascal

Los Espartales

El Casar

Juan de la Cierva

Alonso de Mendoza

Conservatorio

Parque de los Estados



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Foreword



Metrosur – Commuting in the 21st Century



Madrid Metro has come a long way since the first 4 km-long line was opened in 1919. Over the following 75 years, inaugurations of new lines and extensions took the system to 120 km in length. Then, in a rapid expansion programme between 1995 and 1999, another 56 km of lines with 38 stations were added. The existing lines 1, 4, 7, 9 and 10 were extended, and two new lines were started. Line 11 was commenced at the Plaza Elíptica interchange with line 6, and the very important line 8 connection was made between line 4 at Mar de Cristal and Barajas international airport. The latter is now being extended into the centre of Madrid to Nuevos Ministerios, where an airline check-in facility is being built as part of a major transport interchange between metro, suburban railway, taxi and bus services. Very soon it will be possible to get from Madrid city centre to the airport in 20 minutes, without the encumbrance of baggage.

During the 1995-1999 expansion, Madrid successfully established its position as the metro tunnelling capital of the world. Nowhere else have so many stations and tunnels been added to a system so efficiently, quickly, and frugally. The cost per linear kilometre of the Madrid Metro expansion, including rolling stock, came to just \$30.3 million. Compare this with, say, Paris Meteor at \$155 million, or London Jubilee Line Extension at a whopping \$375 million! The government and population were suitably impressed, resulting in a general air of confidence in the capability of Madrid Metro to provide a first rate underground transportation system.

Public support was also secured for the plan to join together five towns to the south west of the city by a 40.5 km-long underground circle line with 27 stations. This new line 12, or Metrosur as it is popularly known, will be connected into the Madrid metro system by an 8 km-long extension of line 10, which is also being upgraded to take new, high-capacity rolling stock.

The great advantage of building Metrosur at this stage, is that the five towns involved are still under development. This makes for easier routing through their centres, and better station location. While the population is well attuned to construction work, wherever possible, the metro construction portals are located away from residential areas, reducing noise and dust pollution, and accelerating work on a 24 h/7 day cycle. Fast-track construction makes the population more tolerant, not just because any nuisance will be out of the way quickly, but also because the benefits will be realised within a quantifiable time span.

The towns themselves are already significant in size, having expanded from villages over the last 20 years. Alcorcón already has 144,000 inhabitants, Móstoles has 197,000, Fuenlabrada has 175,000, Getafe has 148,000, and Leganés has 180,000. Metrosur, apart from linking all five towns together, will also interchange with suburban railway stations, bus termini, hospitals, universities and shopping centres. The extension of line 10 southwards to Alcorcón to connect with Metrosur will provide residents with a fast metro route to the heart of the city.

The young populations of the five towns have seen the values of their properties multiply with the construction of Metrosur, and already anticipate an improvement in their quality of life with its completion. Not only will the new line reduce the duration of their daily trip to work, it will also bind their communities together, giving them a fast, secure and dependable direct link with civic, educational, medical and social amenities. It is a spur to commercial development that will help transform the area from a dormitory into a dynamic new suburb of the capital.

There is no doubt that Metrosur will become the yardstick for future new underground systems. It has a supportive public, a proven design and construction team, top class equipment, and responsible political direction. However, it still takes dedication, skill and resilience to bring such major schemes to fruition. Comunidad de Madrid, which provides transportation infrastructure for the Spanish capital, holds the following caveats: project decisions within 24 h; direct accountability and responsibility; safe construction techniques; early anticipation of problems; continuous cost control; and powerful equipment. This, surely, is the recipe for Commuting in the 21st Century!

Mike Smith, Madrid, September 2001

1999-2003 Metro Enlargement



Over a million people live in the metropolitan area south of Madrid, located in the five large municipalities of Alcorcón, Leganés, Getafe, Fuenlabrada and Móstoles. Historically, these dormitory towns have been largely dependent on Madrid. However, in the last few years, they have started to endow themselves with their own amenities, such as cultural and sports facilities, schools and universities, health centres and hospitals, shopping malls and entertainment venues, evolving into towns with an entity and personality of their own.

Metrosur will support and consolidate this development, by means of a circular underground line linking the five municipal districts. It will be fully integrated with the Suburban lines C-3, C-4 and C-5, as well as Metro line 10, which will be extended from the new Puerta de Batán station, to its connection with Metrosur in Alcorcón. The project is being developed within the framework

of proposals by the Government of the Community of Madrid, as part of the 1999-2003 Metro (Underground) Enlargement Plan. These proposals also include the extension of line 10 to Alcorcón, and line 8 to Nuevos Ministerios.

Metrosur will be 40.5 km-long with 27 stations, six of which interchange with suburban train stations and Metro line 10, and another three of which will be left ready for future expansion. Completion is scheduled over a three-year span from 2000 to 2003, at a total cost of Pta220 billion, or \$1.12 billion. The new line will give direct access to the town centres of Alcorcón, Leganés, Getafe, Fuenlabrada and Móstoles and their hospitals; the Carlos III and Rey Juan Carlos Universities; and service, shopping and entertainment areas. The connections with suburban train services will provide easy links to the municipalities of Aranjuez, Ciempozuelos, Valdemoro, Parla, Pinto, Humanes and Madrid.

The rolling-stock which will be used on Metrosur is the 6000 type, which is the latest design and the one with the greatest capacity.

In view of its size, the project was divided into 12 sections for design purposes, and six sections for tender purposes. Line 10 involved another two sections, one for enlargement and the other for construction, together with the depot at Cuatro Vientos. All station designs are by Juan Alonso.

Contract 1, comprising Sections 1, 11, and 12 with 9.636 km of line and five stations was designed by Proser, Typsa and Intecsa, and awarded to ACS-Vías under the supervision of Eptisa and Aepe.

Contract 2, comprising Sections 2 and 3 with 7.224 km of line and five stations was designed by Euroestudios and Aepe, and awarded to FCC under the supervision of Typsa and Euroestudios.

Contract 3, comprising Sections 4 IIIB, 4A and 4B with 2.688 km of line and two stations was designed by Euroestudios, and awarded to Sacyr and OHL under the supervision of Intecsa and Inarsa.

Contract 4, comprising Sections 5 and 6 with 6.563 km of line and four stations was designed by Typsa and Aepe, and awarded to Necso under the supervision of Proser and Prointec.

Contract 5, comprising Sections 7, 8, and 9 with 7.376 km of line and five stations was designed by Prointec and Ginprosa, and awarded to Ferrovial Agroman under the supervision of Intemac, Geoconsult and Eurocontrol.

Contract 6, comprising Section 10 with 7.043 km of line and seven stations was designed by Proser, and awarded to Dragados under the supervision of Incoydesa and Ingeotec.

Line 10 enlargement for 7.994 km from Alonso Martínez to Puerta de Batán was designed by Inocsa and BB&J, and awarded to FCC and Ferrovial Agroman under the supervision of Sener and control of Geocisa.

Line 10 construction from Puerta de Batán to Alcorcón with 6.774 km of line and two stations was designed by Inocsa, BB&J and Iberinsa, and awarded to Necso, FCC and Dragados.

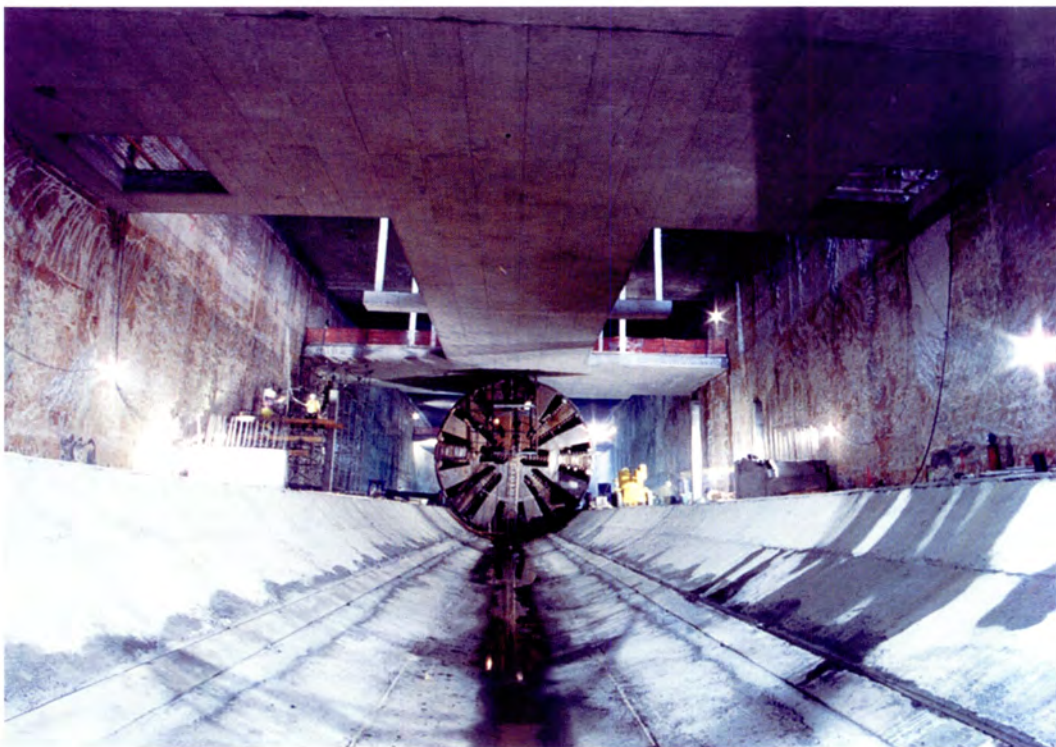
The following report has been collated from inputs by these companies, under the direction of the engineers of Comunidad de Madrid.





METROSUR

Sector: Leganés – Alcorcón – Móstoles



*The value of the
great public works*

ACS Proyectos, Obras y Construcciones, S.A.

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Contract 1 Sections XI, XII and I a

Contractor:



From Leganés to Alcorcón and Móstoles

The XI, XII and I sectors of Contract 1 add up to 9.637 km, and comprise 23.6% of the total length of the Metrosur circle line. The project will cover the transport demand of 50% of the Alcorcón town population of about 141,000 inhabitants.

These important works were awarded to a joint venture between ACS and Vías y Construcciones. ACS was originally involved in the Madrid Metro Line 9 extension, between Pavones and Puerta de Arganda, and is using the same 9.38 m-diameter EPB TBM at Metrosur. This has been a great advantage to the present joint venture, not only for production planning, but also for the availability of experienced, skilled personnel, for both operations and maintenance. This previous experience has improved both the startup and the construction rates, as the main soil characteristics are very similar to those encountered on Line 9.

Project Description

This sector of the Metrosur line passes through the towns of Leganés, Alcorcón and Móstoles, starting with the Leganés 6 station at San Nicasio, and ending at the entrance to the Móstoles 1 station at Los Rosales. The Móstoles 1 station itself is part of the contiguous contract 2.

The first section of 1,726 m in length, starting at the Leganés 6 station and ending at the first shaft, is being constructed using the cut and cover method in open country, outside the town's boundaries. The remaining 7,911 m of tunnel are being constructed using the TBM.

Contract 1 also involves the construction of five stations. One of these stations, Alcorcón 1, is the connection point



between Metrosur and the Madrid Metro Line 10. Another one, Alcorcón 3, is the interchange with the metropolitan surface railway network.

The project allows for the construction of two future stations, one in Leganés and the other one in Móstoles, providing suitable horizontal and rectilinear sections. The Metrosur stations are designed for cut and cover construction, and are located to offer maximum catchment of the transport demand. The cut and cover method permits closer control of the construction costs and deadlines, reducing the risks of time and cost overruns.

According to the principles and criteria devised for the earlier Madrid Metro extensions undertaken between 1995 and 1999, the stations' functionality is increased through avoiding long connection corridors, and through integrating all the facilities within a unique volume, delimited

Tail end of TBM backup leaves a station after jacking through.



Curved section of cut and cover tunnel near Leganés.

by diaphragm walls. According to the same philosophy, the Metrosur stations were designed in suitable locations, at about 14 to 16 m of depth from surface to the rail elevation. The planned depth is governed by the minimum soil cover required at the TBM breakthrough positions. The TBM also determines the ticket hall slab elevation of about 7 m above the rail level.

The project also provides three electrical sub-stations, one located in the first shaft, and the other two in the Alcorcón 1 and Alcorcón 3 stations.

The most important of the affected facilities is the military railway, parallel and coincident with the tunnel in its first 500 m. The railway will be diverted temporarily, and then repositioned on its initial location after completion of the Metrosur works.

Placing the roof beams at a station.



Among the remaining stations, the positioning and characteristics of Alcorcón 1 station affect a number of important facilities. Prior to the start of the works, the diversion of facilities such as water and gas pipelines, electrical lines and wastewater conduits was undertaken, and several traffic restrictions had to be imposed at different stages.

The first shaft is located within Leganés town limits, at about 1.7 km from the start point of the contract. Work on the second shaft started early, at a location situated at about 5 km from the first shaft, in order to reduce the supply line length during the tunnel completion. The TBM will be taken out through a third, much smaller shaft, before reaching the Móstoles 1 station.

Railway Design

The EPB tunnel is being excavated in a 9.38 m circular section with a reinforced concrete lining of 8.43 m internal diameter rings, each formed by 7 curved elements, 0.32 m thick. The annulus between the concrete rings and the excavation is injected with cement grout.

The cut and cover tunnel is being built with diaphragm walls and superior and inferior vaults. The tunnel width, or horizontal distance between the diaphragm walls, is 7.8 m, and the maximum height is 6.5 m. The height of both types of tunnel is designed to allow twin-track railway passage of the new 6000 series trains.

The railway design criteria have been established by Metro de Madrid. The design is constrained by the location of the stations; the geotechnical characteristics of the soils; the connection and design conditions compatible with contiguous sectors; the Metrosur – Line 10 crossing; and functional aspects, such as facilitating the users' access from the exterior by placing the platforms as close to ground level as possible. The urban structure, and particularly individual building foundations, have to be taken into account, together with the geography of existing facilities. It is also intended to minimise the distances inside the Metrosur – Line 10 and Metrosur – metropolitan railway interchanges.

The design criteria are: minimum curve radius 300 m, exceptionally 280 m; maximum gradient 3.5%; minimum vertical connection radius: $K_v = 2,000$ m; length of stations: minimum 115 m; transversal level difference of the railway: maximum 150 mm; uncompensated transversal acceleration: 0 m/s, exceptionally a maximum of 0.65 m/s; transversal acceleration variation in transition sectors: 0.17 m/s^3 , exceptionally a maximum of 0.20 m/s^3 ; heights corresponding to the 6,000 series train; railway transversal slope: 1.5 mm/m, exceptionally 2.0 mm/m.

The geotechnical study carried out for this sector defined the ground as typical Madrid subsoil, with sands, clayey sands and sandy clays.

Difficult Structures

Leganés 6 station is located on the limit of the San Nicasio neighbourhood, in a zone characterised by a high urban development process. It has two accesses from the street level to an underground hall that forms the first station level. The access to the station platforms from the hall is by means of stairs and mechanical elevators.

Passengers' routes were minimised, and facilities integrated, to provide a unitary vision from inside the station. The architectural solution is based on the double height perception, which allows a better survey of the traffic.

The cut and cover solution was chosen in order to place the station below the military railway, which has been diverted. The dimensions of the station structure are delineated by the 0.8 m-thick diaphragm walls, which form an enclosure some 129.4 m-long, with a maximum width of 33.8 m. The roof slab of the station is calculated to support both a 1.30 m-deep earth embankment, and the anticipated military railway traffic loads.

Alcorcón 1 station is the most difficult construction, due to the requirement for a double station, as the interchange between Metrosur and Line 10. It is a cross-shaped station, where the lower line corresponds to Metrosur, and the upper one to the metro Line 10.

The Metrosur section of the station is 128 m-long, and is at depths ranging from 22.13 m to 22.55 m from the ground level. The Line 10 station has a total length of 120 m, and is located between 13.52 m and 14.10 m-deep.

The structure is a continuous, 0.8 m-thick, diaphragm walled enclosure. The roof is formed by prefabricated beams, which support the loads from a 0.80 m to 1.50 m thick earth embankment, as well as from traffic and other urban facilities.

The station has three accesses to its two main halls serving Line 10, and the Metrosur platforms are accessed by means of stairs and mechanical elevators in both circulation directions.

The TBM excavated through the Alcorcón 1 station. The complexity of the station structure, and its proximity to the first shaft, resulted in the machine reaching the station before excavation of the box had been completed. The prefabricated segmental rings of the tunnel lining were removed once the station excavation reached the invert elevation of the tunnel.



Alcorcón Stations

Alcorcón 2 station is 125.20 m-long, and is positioned some 13.57 m to 15.84 m deep, below the Avenida de Leganés, and between the Principe Don Juan Carlos and Avenida de Lisboa streets. It has a unique access, located in the Avenida de Leganés. It is a rectangular-shaped station, due to its proximity to the neighbouring buildings, and was roofed with a cast *in-situ* reinforced concrete slab.

Alcorcón 3 station is an interchange station between Metrosur and the existing metropolitan railway station. It is located in the Avenida de Móstoles Street, and also caters for the Alcorcón Hospital demand. Its shape is similar to most of the Metrosur stations: rectangular with a sensible widening to permit the staircase location. The roof is formed of prefabricated beams, and the mezzanine level was cast *in-situ* from reinforced concrete. An underground passage will allow access to both platforms of the station from the metropolitan railway station.

Alcorcón 4 station is located within the Juan Carlos I University and next to the Alcorcón Parque Oeste commercial centres. It is placed completely underground, and has one access covered by glass pavilion, linked to the platforms by means of mechanical elevators. The general concept is similar to the Alcorcón 3 station.

EPB Excavation

For the tunnel, the choice of the construction processes was based on previous experience, acquired during the completion of

Beamed roof and invert slab with mezzanine support pillars at Alcorcón 3 station.



Applying the waterproofing layer to the external roof of the cut and cover tunnel.

the Metro de Madrid extension plan from 1995 to 1999.

In this particular case, this expertise has a special significance, not only in terms of geotechnical properties of the soils, but also with regards to what is considered to be the best experience to date, worldwide. The previous works yielded exemplary results, with high construction rates and early completions, bettering the most optimistic predictions. The costs were substantially lower in Madrid than those of the closest available references in London, Athens and Lisbon.



Crane positions the final beams to close a station roof.

The Metrosur Contract 1 sector is being constructed using a 9.38 m-diameter EPB TBM, working with or without earth pressure, to produce a tunnel with an 8.43 m internal diameter reinforced concrete segmental lining.

Each lining ring is made of seven curved segments, 0.32 m thick and 1.50 m wide. The gap between the excavation surface and the concrete rings is injected with cement grout, having the double function of spreading the ground pressures evenly, and waterproofing the tunnel. Waterproofing is also enhanced by means of neoprene gaskets on the segments.

The segment fabrication facility is located close to the first shaft. The plant is designed for a production of 18 rings/day, and has a storage capacity of 585 complete rings.

The total length of the TBM is 125 m, and its weight is around 1,500 t. To advance, the machine uses the forward pressure generated by 13 pairs of hydraulic cylinders, which react against the last-placed ring. To get excavation underway from the start shaft, a steel reaction frame was erected at the tunnel portal.

Cut and Cover

The section of tunnel between the Leganés 6 station and the first shaft was constructed by the cut and cover method. First, the diaphragm walls were installed, followed by placing of the concrete roof. Once the upper vault was completed, excavation between the diaphragm walls was possible, and the invert could be concreted.

Two construction methods were used. The one method involved excavating a trench down to the top of the diaphragm wall, or to the covering vault level. The main advantage with this method is that no shear stresses are transmitted to the diaphragm walls. In the second case, braces are placed across the diaphragm walls in order to support the vault and transmit the shear stresses from the ground. The diaphragm walls and upper vault are 0.60 m thick, while the inferior vault is 0.50 m thick.

The stations are constructed from the surface in a diaphragm walls and piles enclosure. After removing the piles and diaphragm heads, the ground is excavated down to the main hall elevation, and the station roof formed using prefabricated beams. Excavation is then undertaken to reach the invert elevation.

The Alcorcón 2 station is covered by a concrete roof, which was placed *in-situ* before excavation commenced, in order to keep any deformation within an acceptable range. With the exception of the Alcorcón 1 station, all of the stations were completed before the TBM drive reached them. **TS**

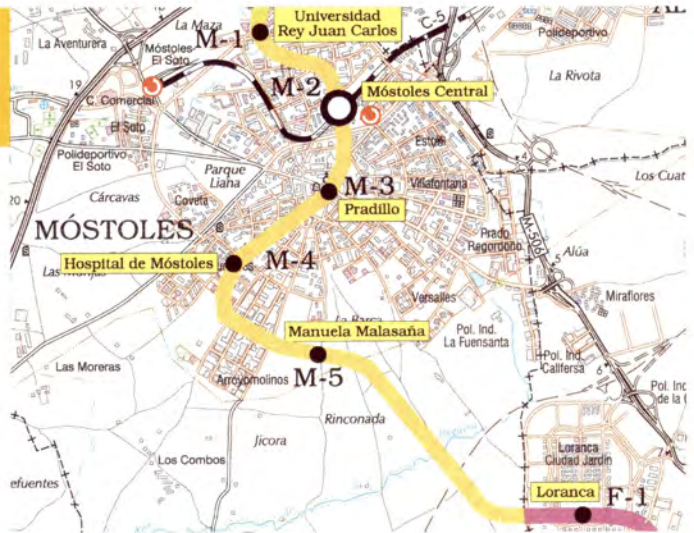
Contract 2 Sections II and III

Contractor:



Construccion, SA.

Tunnelling Beneath Móstoles



Section II of Metrosur contract 2 runs beneath the urban neighbourhood of Móstoles, with a length of 3,173.8 m, starting at the screen wall entering the siding yard located before the Móstoles-1 station, and ending at the entry gable of the Móstoles-4 station. Section III is located within the districts of Móstoles and Fuenlabrada, with a length of 4,128.8 m, starting at the entry gable of the Móstoles-4 station and ending at the P.K. 4/160 to the west of Loranca.

In total, the length of Contract No. 2 is 7,302.6 m, in which five stations, five tunnel ventilation shafts, four emergency exits and two pumping shafts have been projected, as well as a link tunnel to access the future wagon sheds located in Loranca.

Route and Sites

The contract began with the construction of the Móstoles 1 station, located close to the Rey Juan Carlos I University Campus, underneath the Tulipán and Alcalde de Móstoles streets, where its access is situated. Four sidings have been projected within the station enclosure, for the temporary parking of rolling stock on both sides of the platforms. The depth varies between 14 and 22 m to track level.

The line tunnel that runs underneath the Parque Estoril II residential area, at a depth of between 12 and 28 m, begins at the exit of the station. The ground route traces a left-hand curve with a radius of 300 m, which connects with a right-hand curve with a radius of 310 m, until reaching the entry gable of the Móstoles 2 station, located



behind the Renfe tracks of the C-5 Suburban network line. The length of the tunnel between stations is 1,122.5 m. A continual incline of 2.1% is maintained in terms of elevation. One emergency exit,

Aerial view of TBM launch pit at Móstoles 5 station.



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Solely a leading construction and services Group, the number one in Spain, is capable of breaking the world tunnel-building record. To accomplish this, the FCC Group's "La Adelantada" tunneling machine has set the mark of 1,020 meters of tunnel built in one month's time in the Madrid subway expansion project for which FCC is building 12,000 meters of tunnels and eight modern new stations. This record is the result of our technological capabilities.

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MAKING HEADWAY INTO THE FUTURE

and one ventilation shaft in the PK 0/820, are located in this inter-station section.

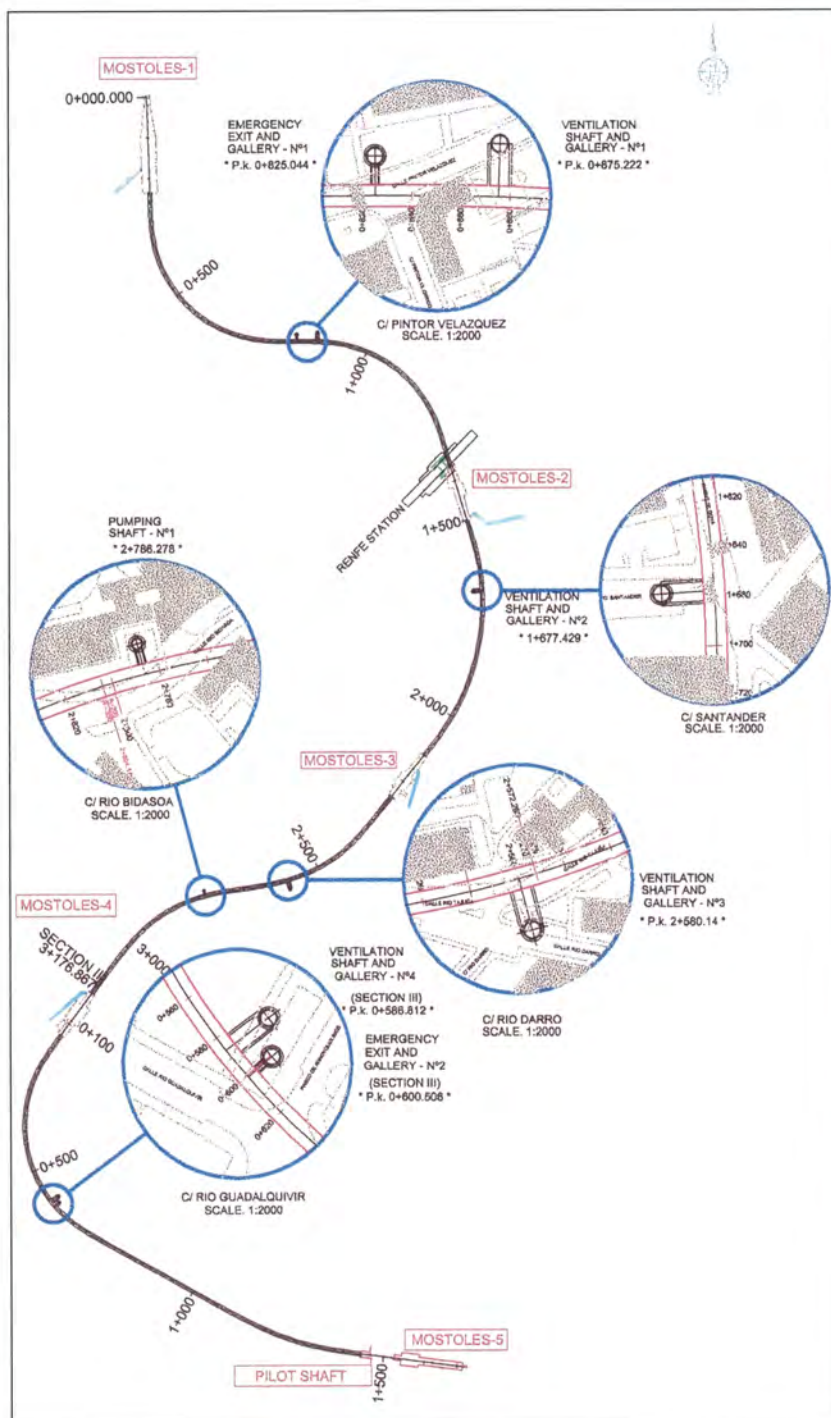
The Móstoles 2 station occupies a space between buildings in Paseo de Goya, next to the existing Renfe station in Móstoles, at a depth of 18 m, and involves a passenger interchange, with widening and restructuring of the existing Suburban station.

The line tunnel ground route at the exit of the Móstoles 2 station traces a right-hand curve, with a radius of 545 m, for 612.90 m until the Móstoles 3 station, located under the Plaza del Pradillo, in the historic centre of Móstoles. The tunnel elevation begins with a 3.5% slope in the initial section, ending with 0.5% on the final section, at a depth varying between 18 and 25 m. There is a ventilation shaft in the PK 1+680.

The exit tunnel of the Móstoles 3 station traces a right-hand ground plan curve, with a radius of 375 m, changing to a left-hand reverse curve, with a radius of 300 m, connecting with the straight track of the Móstoles 4 station. The length of this tunnel between stations is 932.60 m, with a depth varying between 13 and 24 m. The section starts with a 3.5% slope until it reaches the PK 2+787, where a low point is created. From here, a 3.5% incline begins, climbing to the station gradient, running underneath the buildings in the old quarter of Móstoles. There is a tunnel ventilation shaft in the PK 2+569, and a pumping shaft in the PK 2+788, in this inter-station section.

The Móstoles 4 station is located underneath the Villa Europa Park, situated between the Río Sella and Río Ebro Streets, at an average depth of 16.5 m. The needs of passengers visiting Móstoles General Hospital have been taken into account when locating its access.

The tunnel section between the Móstoles 4 and Móstoles 5 stations is 1,376.8 m-long. It starts with an extension of the station track into a left-hand curve, with a radius of 300 m. This connects with the straight alignment of Río Guadalquivir street, under which it runs until it reaches the building land known as PAU-4. Here it turns to the left, on a curve with a radius of



Metrosur sections 1 and 2 showing stations and service shafts.

Móstoles 1 station slab preparation for casting concourse.



Roof slab concreting at Móstoles 3.

700 m, to connect with the Móstoles 5 station. In terms of elevation, the tunnel begins with a 0.82% incline, and ends in the last 500 m with 2.14%. The tunnel depth varies between 9 and 26 m to track level. There is a ventilation shaft in the PK 0+897, and an emergency exit in the PK 0+904.

The launch shaft for the TBM is located in the entry gable of the Móstoles 5 station, on the alignment of a future false tunnel. The Móstoles 5 station itself is located in the PAU-4 area, at a depth at track level of between 10 and 12 m.

From the exit of Móstoles 5 to the end of the route, 2,496 m of tunnel are projected. This section starts with a 650 m radius right-hand curve until the PK 2+400, connecting with a 710 m-long straight track that runs parallel to the road from Móstoles to Humanes. This connects with a left-hand curve until joining the Loranca Avenue alignment at the boundary line between

Screen wall installation at Móstoles 4.



the districts of Móstoles and Fuenlabrada. This alignment then extends to the intersection with the Pablo Iglesias Avenue, where the work in Contract 2 ends. The link tunnel for the proposed future wagon sheds in Loranca is located on this last part of the alignment.

Rising from the exit of Móstoles 5 on a 0.5% slope, this increases to 2.65% at 590 m until it reaches the PK 2+875, where there is a low point from which a 0.1% incline starts at 765 m, increasing to 3.3% in the last section. There are two emergency exits in the PKs 2+533 and 3+256; a pumping shaft in the PK 2+892; a tunnel ventilation shaft in the PK 2+977; and two rivers are channelled over the tunnel in PKs 2+920 and 3+705, to avoid erosion. The average depth of the tunnel varies between 12 and 14 m.

Geotechnical Description

The land traversed by the new Metrosur line includes formations that are typical of Madrid. Specifically, in the project section, detritus material is located included in the facies of Madrid. This originated from the erosion of granite and metamorphic reliefs in the Sierra de Guadarrama, produced by widespread flooding. This is partially covered by other quaternary materials of colluvial origin, and by anthropic fillings.

In terms of the research carried out, together with existing data, 30 exploratory boreholes, with the continuous extraction of samples, were carried out at the design stage, and another 20 boreholes at the work stage.

In agreement with the classifications of ground in Madrid, four types of different material have been distinguished corresponding to the Tertiary age, as well as quaternary anthropic fillings and alluvial deposits. The nomenclature used, and the classification criteria, are as follows: Fillings; Alluvial; Miga sand (fine < 25%); Tosquiza sand (25% < fine < 40%); Sandy Tosco (40% < fine < 60%); and Tosco (fine > 60%).

In the projected section, the sandy and clayey levels alternate. At the start, and up to PK 2+100, alternations of sandy tosca and tosquiza sand predominate. Between PK 2+100 and PK 2+800, toscos prevail. Between PK 2+800 of Section II and PK 1+100, strata of miga sand alternating with tosquiza sand have basically appeared. Between the latter point and PK 3+100, there is a succession of tosquiza and sandy tosco levels and, in the final section, alternations of miga sand and tosquiza sand prevail. On the surface, anthropic fillings of up to 8 m in thickness have been located, along with alluvial soils with a depth of up to 5 m. Numerous water levels have been detected, which are retained over more impermeable lower substrates.

Design Criteria

The design criteria established for the Metro Plan 1999-2003 have respected the parameters defined in the previous plan, improving the geometric route parameters to adapt them to type 6000 rolling stock, considering all of the improvement determinants for the user, in terms of both functionality and safety. The sites of the stations have been specifically studied, along with the geotechnical characteristics of the soil, and the functional aspects of ease of access from outside. Platforms are as close to the surface as possible, minimising runs, and making easier interchanging with existing suburban networks, services, and the urban structure.

The geometric parameters for the design of the route and the track are: minimum ground plan curve radius, 300 m; maximum incline, 3.5%; minimum vertical agreement, Kv 2,000 m; alignment at stations, horizontal and straight, minimum length 115 m.

Construction Methods

The construction methods determined for Contract 2 are differentiated in two large groups, according to effects on the surface. The underground section, comprising EPB tunnels and four stations between screen walls, accounts for 63% of the work. The cut and cover section, comprising false tunnel, tunnel between screen walls, and one cut and cover station, accounts for 37% of the works.

The underground section begins at the Móstoles 1 station and ends at the pilot shaft located next to the Móstoles 5 station, with a length of 4,958 m.

The tunnelling methods employed along this section are: line tunnel – EPB TBM; shaft and gallery – traditional Madrid Method; stations – screen wall enclosure using the upward-downward system and cut and cover.

Line tunnel boring is carried out using a 9.38 m-diameter EPB tunnel-boring machine, which is the safest method for both operators and buildings. This method presents the complete mechanisation of the processes of excavation, lining and injection.

TBM Excavation

The machine consists of a large cutting head with the same diameter as that to be excavated, 25% of its surface being taken up by the cutting discs. When the cutting head turns on its shaft, whilst pushing against the ground, the excavated ground is forced into the EPB chamber. Here it is treated with biodegradable foam, creating a mousse that maintains the pressure on the working face.



La Adelanta TBM installation at Móstoles 5 station.

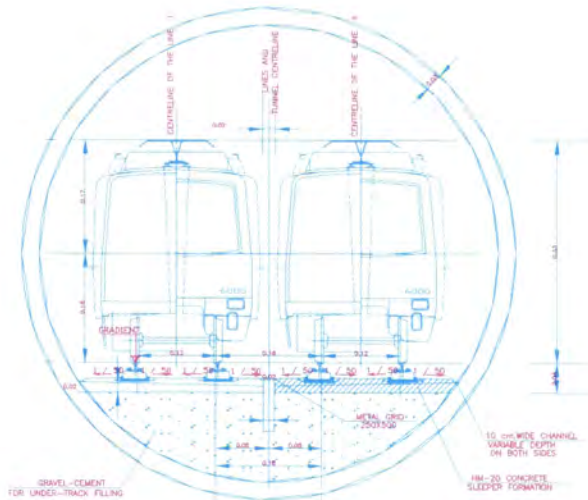
The cutting head is followed by a shield, within which the tunnel lining is erected. The lining consists of seven precast reinforced concrete segments that form cylindrical rings, with an internal diameter of 8.43 m, 1.50 m in length and 0.32 m in thickness. The segments are fitted with waterproofing gaskets around their perimeter, and are joined together with steel bolts.

Forward motion is generated by means of hydraulically-powered jacking cylinders, which push against the last ring of the positioned lining.

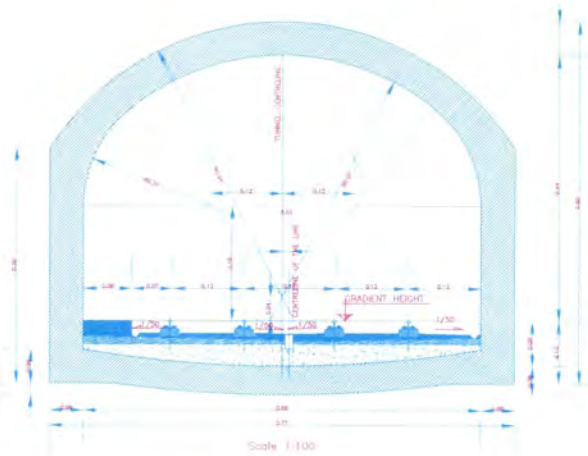
The process is as follows: the shield is launched from the pilot shaft using an anchored steel reaction frame; ground is excavated by the rotating cutting head

Cleaning up in completed TBM tunnel.

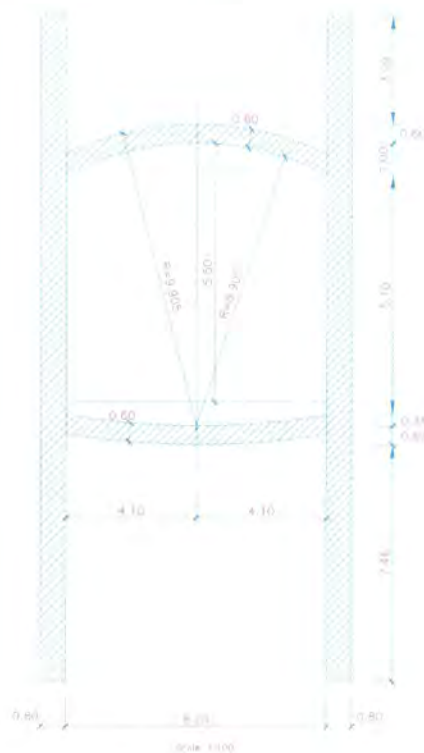




Scale 1:100



Scale 1:100



Scale 1:100

Tunnel sections: (top) EPB, (centre) false, and (bottom) between screen walls.

discs under pressure from the jacking cylinders; the lining ring is erected once the excavation cycle is finished. This process is repeated until the tunnel is completed.

The main characteristics of the machine can be summarised as follows: pushing jacks, 26 cylinders with 320 mm-diameter pistons; total pushing force, 10,000 t; feed rate 0-80 mm/min; cutting tools, 148-pick cutting wheel, double 17" disks and two copy cutters; cutting wheel drive, 16,000 kNm torque; initial starting torque, 20,000 kNm; installed output, 2,000 kW; maximum rotation speed 2.4 rpm; 4,950 mm diameter bearing; electrical installation, 15 kV feed; installed output, 3,700 kVA; guidance system, Leica electronic laser.

The extraction system is a spiral auger conveyor with an external diameter of 1,000 mm. The spoil transport capacity is 663 cu m/h on a 1,200 mm conveyor belt with 1,200 cu m/h capacity. The mortar injection system has double injection pipes between the rings of segments and the ground and has a capacity of 5.6 cu m/h.

Madrid Method

This method is used to excavate connections from the line tunnel to the ventilation and pumping shafts and emergency exits. The manual excavation rate can be adjusted to the ground conditions, using planks, metal bracing and wooden props for temporary support. The construction sequence is as follows: excavation of an auxiliary advancing gallery in the top of the tunnel, shored with planks, wooden props and metal bracing; widening of the advancing gallery until the entire section is excavated, completing the shoring; lining and concreting of the arch; benching excavation with a phase difference in relation to the face; excavation and concreting of the sidewalls, using abutted supports to prop two adjoining half-rings of the arch; excavation and concreting of the tunnel roof; and roof annulus injection. The length of the ring, or incremental advance, is decided according to the ground conditions.

Stations Between Screen Walls

In the Móstoles 1, 2, 3 and 4 stations, a large screen wall enclosure has been designed and configured, covered by reinforced concrete slabs, using the cut and cover technique.

The planned construction stages are: service siding, service platform formation and rail kerbs; excavation and concreting of screen walls and pile stacks; support surface preparation, steel reinforcing and concreting of the roof slabs; restoration

of the surface for urban use; interior excavation up to concourse slab support height; repair of support surface, steel reinforcing and concreting of the concourse slabs and rams; excavation to roof height; shuttering, steel reinforcing and concreting of the roof ready for passage of the tunnel-boring machine; construction of interior structures, stairs and platforms; and masonry, installations and finishes.

Cut and cover

The cut and cover section begins with the launch shaft located next to the Móstoles 5 station, and finishes at the end of the Contract in Loranca. It comprises entirely false tunnel through open country, housed in a cutting excavated for the purpose. The construction stages are: excavating up to the lower height of the slab; reinforced slab shuttering and concreting; installation of the shuttering formwork for the entire section; frontal shuttering; steel reinforcing and concreting; waterproofing of sidewall and roof extrados; and filling and compacting of ground to natural land height.

Tunnel Between Screen Walls

Within the excavated section for the false tunnel, there are various areas with isolated buildings that prevent the excavation of the cutting necessary for the construction of the false tunnel. In these places, screen walls are necessary, with the following work components: formation of service platform and rail kerbs; excavation, reinforcing and concreting of the screen wall constituting the sidewalls of the tunnel; installation of fastening beams at the crown of the screen wall; open-pit excavation to lower surface height of roof; support surface preparation; shuttering, steel reinforcing and concreting of the roof; filling and compacting of ground to natural land height; internal excavation of the tunnel to roof height; and floor cleaning, reinforcement, screen wall anchoring and concreting. In the case of tunnels at any great depth, intermediate shoring is required.

Station With Open-pit Excavation

This system was used in the construction of Móstoles 5 station, with the following stages: cutting excavated to lower slab height; foundation shoe and slabs laid; perimeter walls cast in the concourse area, and roof on station body; centring and laying of concourse and roofing slabs; and ground filling to natural land height. The method is completely opposite to that of the screen wall station.



Ground Treatment

The detailed study of the buildings affected by the tunnel alignment was translated into the definition of the areas with a potential risk of settling, in which land treatments were projected to counteract possible subsidence induced by construction of the tunnel. Four types of treatment have been used: compensation grouting – underneath buildings crossed by the tunnel with little lining; jet-grouting columns – next to buildings affected by settlement coverage; micro-pile screen walls – next to buildings with superficial foundations cutting settlement coverage; mortar piles and screen walls – EPB TBM repointing.

The period for work implementation is 30 months as of signing of the location record on 23rd May, 2000, work completion being foreseen for 23rd November, 2002. The programmed terms are being met, as of 15th July, 2001. 

Roof concreting between screen walls.

TUNNELS

1995 – 1999

EXTENSION OF THE MADRID METRO

1999 – 2003



Comunidad de Madrid

CONSEJERÍA DE OBRAS PÚBLICAS,
URBANISMO Y TRANSPORTES



NECSO, Entrecanales Cubiertas is currently building almost 8 kilometres of the new Metrosur circular line in Madrid.

We also recently completed 5.86 kilometres of tunnel for line 8 - 3,366 metres using a tunnelling machine and the remainder by the "Madrid Traditional Method".

Once all sections have been built, we will have built over 30 kilometres of tunnel in the Madrid Metro extension since 1995, including 18 kilometres using EPBS (earth-pressure balance shields).

On line 7, the La Paloma tunnelling machine drilled 3,435 metres of 9.38 meter diameter tunnel, and in just one month it drilled 618 metres of tunnel on a curve of radius 275 metres, setting a world record at the time.



entrecanales cubiertas



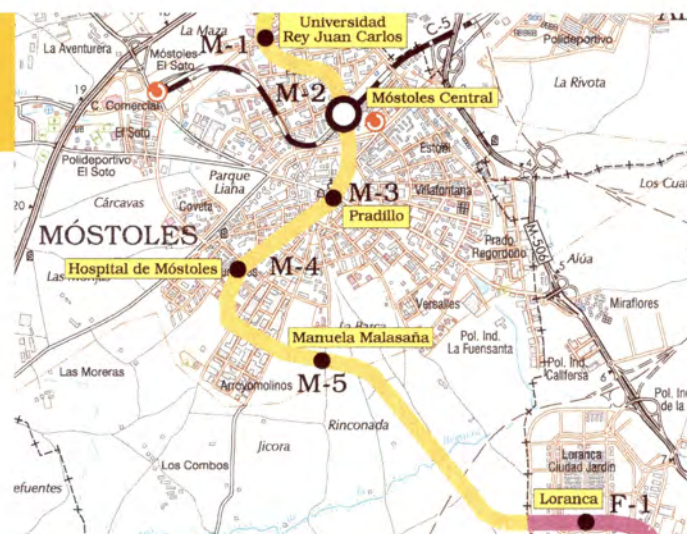
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Contract 2 Section III, B1

Contractor:



Cut and Cover Between Fuenlabrada and Móstoles



In April 2001, part of section III between km 2.84 and 4.16 was awarded to Necso Entrecanales Cubiertas. This section is 1,320 m-long, of which roughly 1,100 m is in Móstoles, and 220 m in Fuenlabrada. It includes the line tunnel, two emergency exits, a pumping shaft, a ventilation shaft and three junctions for the future depot.

In the Fuenlabrada area, the tunnel runs at depths of 16 to 18 m under developed areas, with buildings of heights up to four floors. In the Móstoles area it runs beneath undeveloped land, and crosses the Fregacedos and Reguera gullies, and the future Radial V road.

Geology and Geotechnics

The catchment area, which occupies most of the province, is known as the Cuenca de Madrid, and forms part of the Tagus river basin. It is filled with layers of Tertiary sediments of significant thickness, whose character varies according to the position in the catchment. Three types of facies can be readily distinguished: the Madrid facies, consisting of arkosic sand of varying grain size, and grey-brown or brown clay, locally identified with coarse sand and hardpan; the Intermedia facies, consisting of highly-plastic brown and green clay, or peñuelas, with intermittent layers of micaceous sand; and the Central facies, of a chemical nature, consisting of chalk and chalky marl.



Section III is entirely located in areas of hardpan and sandy soils associated with the Madrid facies. One of the main characteristics of these materials is the structure. They cannot be classified as different strata, but appear as a group of lenticular deposits of differing lateral continuity, which overlap and alternate with sandy and clayey deposits. This makes it difficult to correlate their position at different points.

Curved cut and cover section under construction.



Interior view of curved section.

Plan of section IIIB showing junction telescopes in green.

On this section, the clayey soils predominate over the sandy layers, although, in some areas, the latter are present in considerable thickness. Quaternary alluvial deposits overlie the Tertiary material in the bottoms of valleys, accompanied by anthropic fill, usually of little thickness, in urban areas and their surroundings.

The lithological features are as follows: Quaternary: compacted fill; uncompacted anthropic fill; and alluvial. Upper/lower Quaternary: coarse sand; hardpan sands;

sandy hardpan; hardpan. These features are shown in the geological-geotechnical profile.

Alignment Design Criteria

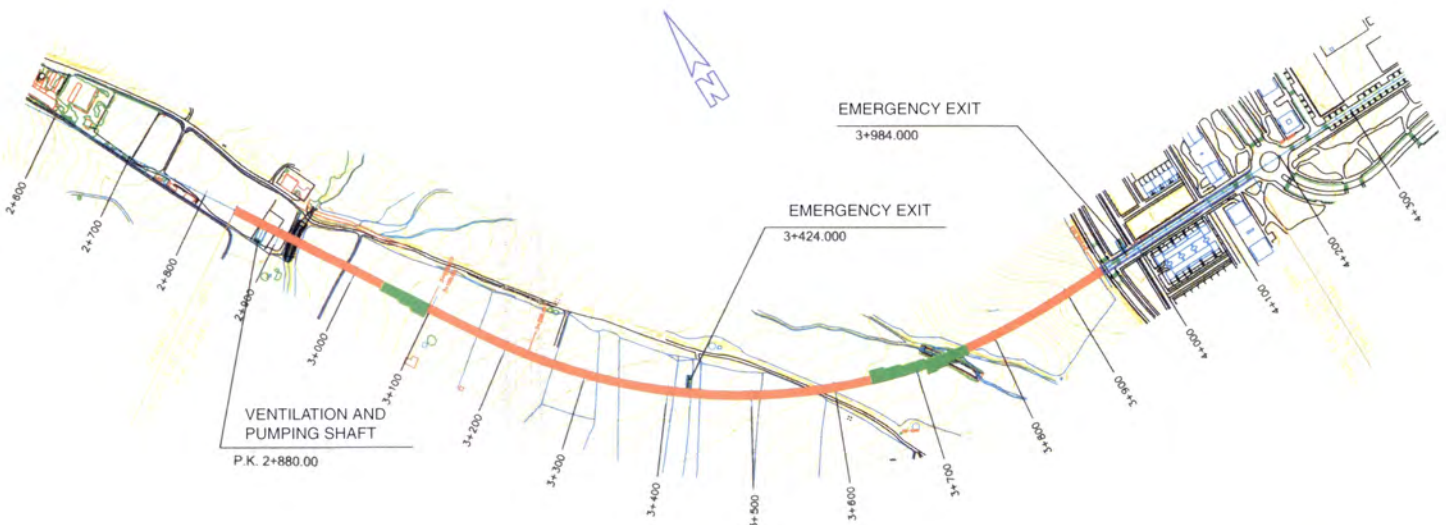
The rolling stock that will be used on Metrosur is the 6000 type, which is the latest design, and has the greatest capacity. This determines the minimum geometric characteristics of the alignment, and the larger size allows carriages to be evacuated faster in the event of accidents.

To provide sufficient cross-section for the 6000 Series rolling stock, the alignment has to comply with stricter conditions than for the rest of the network.

The contract can be divided into two clearly different parts – in kilometre order. The first 1.1 km, between the Reguera Gully and Paseo de Loranca, runs at a depth of 14 m beneath undeveloped land in Móstoles. The tunnel is being constructed using cut and cover. This section crosses the Fregacedos and Reguera Gullies, which have been diverted. From Paseo de Loranca to the end of the contract, for 220 m, the tunnel is being constructed between cut-off walls. This section runs under Calle Alegria in Fuenlabrada, and has buildings on either side.

Monitoring equipment will provide information on movement, on the water table, and on other data which help to detect the behaviour of the structure, and measure any possible deviation from the anticipated parameters.

This equipment includes levelling benchmarks on the surface, gauges on buildings, convergence marks in tunnels, ceramic pressure sensors where water is expected, and pressure cells in the roof and floor. These devices have been fitted to all of the buildings affected by construction.



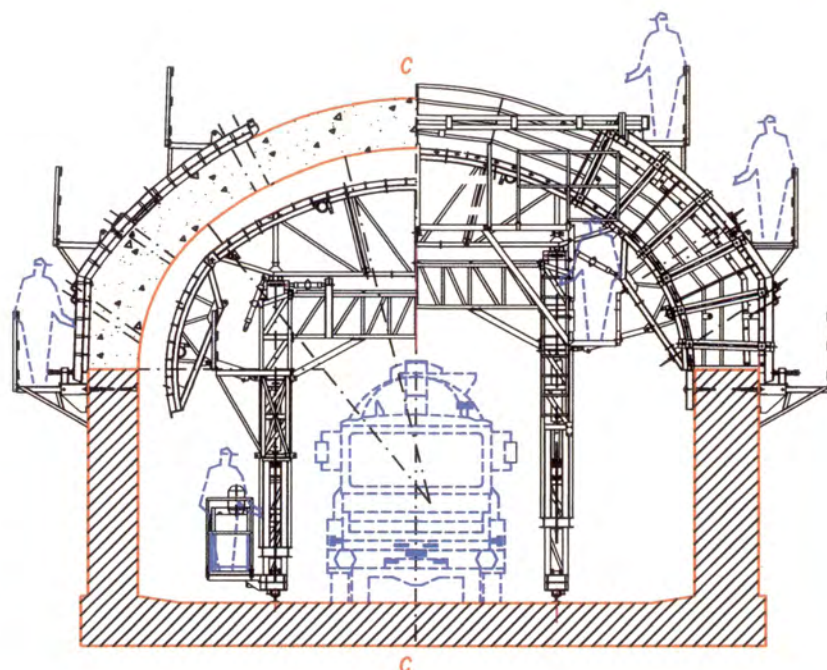
The principal quantities of the contract are as follows:

False tunnel	1,100 m
Tunnel between cut-off walls	220 m
Excavation	449,000 m ³
Fill	270,000 m ³
Cut-off walls	6,131 m ³
Prefabricated beams	1,080 m
Concrete	70,000 m ³
Steel bars	2.8 t
Rail	5,500 m
Elastic spikes	5,500 u

The official estimate came to E21,577,330 and the contract was awarded at E20,463,940 (E = Euro). The contract duration is 20 months from the date of the survey on 24th May, 2001, so work should therefore be completed by 24th November, 2002.

The contract planning was based on the following outputs: open cut tunnel, 100 m/month; cut-off walls, 80 m²/day per team; superstructure, 700 m/month.

The construction methodology for open cut is sequenced as follows: floor slab; haunches using traditional formwork; roof using mobile formwork. After construction has been completed, the excavation is back-filled and the surface restored.



Transverse section of roof formworks.

For tunnel between cut-off walls, the procedure for the excavation is cut and cover. It consists of the following steps: the cut-off walls; roof slab; excavation down to arch soffit level; construction of the arch.

For the depot junction the construction steps are: foundations; walls; placement of prefabricated beams; upper slab; back-fill. 



Casting the floor slab of the three-track telescope section.



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Contract 3 Section IV, Sub-Section IV-B

Contractor: **OHL**



Loranca to Fuenlabrada in Cut and Cover

Sub-section IV-B, which forms part of Section IV of Metrosur Contract 3, consists of a cut and cover tunnel from the Loranca football ground to the Fuenlabrada 2 station, and includes construction of the station. The entire route lies within the bounds of the Borough of Fuenlabrada, and, throughout its length, it runs either under land for which planning permission has been granted, or where construction has already taken place. Building work has already been carried out above the first 118 m of the route, and is scheduled to take place along the remainder.

Project Description

The works commence at km 0+820, at a point opposite the outer walls of the Loranca football ground, and they finish at the exit to Fuenlabrada 2 station, which is located at km 2+687.75. The total length of the section is 1,867.75 m. The contract estimate is Pta 6,509,544,735, and the works are being carried out over a period of twenty months.

The alignment runs through two distinct zones. As far as km 0 + 938, it runs within the Loranca Residential Area. Beyond that point, to Fuenlabrada 2 station, it runs through open country, where only a few isolated buildings are currently located, but plans have been made for construction here in the future.

The first section of the tunnel is straight, as it leaves the football ground. This is followed by a bend, and a reverse curve of radius 500 m. At this point, the tunnel leaves the Loranca Residential Area and enters the open country zone. In this



section, crossings beneath the municipal football ground at km 0+910, and the Paseo de Loranca at km 0+925, have to be dealt with. Once the line is beyond the residential area, the alignment makes use of a gap between a cafeteria and an electricity substation, causing no inconvenience to either of the two facilities.

In the open country zone, the alignment has to take account of the isolated buildings that already exist, while the tunnel also has to be straight. It will run level, as close as possible to the centre of gravity of the zone for which development plans have been made, so that when these building plans materialise, a station can be constructed. This will give future residents easy access to the metro system, once the size of the population warrants building the station.

With a view to this, the section of tunnel between km 1+502 and 1+740 has been

Constructing a tight curve outside Fuenlabrada.



Travelling roof formworks in open cut.

laid out with a straight alignment that is both sufficiently long and horizontal, within which the station can be located. Both location and layout are suited to the development that is to eventually take place. It is planned that the station will lie at a depth of 16 m to the running rail.

Following on this straight stretch, the tunnel will once again have a layout in the form of an "S" with two bends that have radii of 500 m and 300 m, leading to the entrance to the Fuenlabrada 2 station.

Fuenlabrada 2 Station

This station is located between Fuenlabrada Hospital and the Rey Juan Carlos I University campus, both of which are currently under construction. It lies on a straight stretch of alignment, with a horizontal gradient, and a depth of 15.5 m to the running rail.

Emergency exits and shafts will be located at the following points: emergency exit at km 0+936; pumping and ventilation shaft at km 1+624; emergency exit at km 2+140.

Fuenlabrada 2 station is located within the confines of the new hospital plot. One of the station exits will lead directly into the hospital grounds, and the other one will be located on the opposite side of the new Molino road linking Fuenlabrada and Loranca, where it will provide access to the University campus.

The structural design has made it possible to develop a station area that lies within one single space, formed by a box enclosed by the concrete walls. The passenger access routes have been made as simple as possible. There is only one intermediate level between the platforms and the street, and this is where the station foyer is to be situated. The passengers will be able to see the station platform level from the foyer, which will help them to get their bearings.

The platforms are 5.3 m wide, and their working length is 115 m. Two 1 m-wide escalators are located halfway along the platforms, on either side of a 2.75 m-wide staircase.

The emergency staircases are located at the end of the platforms. Access is gained to them from two separate hallways, so the staircase constitutes a protected evacuation area. A gate located at ground level will provide access out into the street. It will be operated by counterweights.

Geological Characteristics

The geological and geotechnical characteristics of the ground are a result of the different types of materials encountered by the excavations, and the following units can be distinguished.

Anthropic fills: this type of ground has been found sporadically, and the maximum thicknesses that have been detected are 2.5 m. They are made up of sand with a variable clay content, and the density of the deposits is slight to average.

Colluvial and alluvial deposits: these are Quaternary deposits that are up to 5 m thick. They are made up of material that is of average thickness in most cases.

Miga Sand: this is characterised by its coarse grain size, its very low fines content, and its light beige colour. Its relative density is high, and maximum thickness is 3 m. Miga sand containing water has been observed on the odd occasion.

Tosquiza Sand: these units are lens-like in nature, and consist of sands and a fines content ranging from 25% to 40%. The relative density is generally very high. A maximum thickness of more than 4 m has been detected. Some of these sandy levels are saturated with water, thereby constituting aquifers that are suspended in the heart of the levels with the highest clay content.

Sandy Tosco: this formation is rather abundant throughout the entire zone, and it is composed of dense to very dense sands, and hard to very hard sandy clays. As a general rule, the plasticity of these materials is average, but it is high in specific zones, and the fines content ranges from 40% to 60%. The maximum thickness is 10 m.

Tosco: there is also considerable evidence of this formation throughout the section. This material is made up of clays, together with a variable sand content, hard to very hard, the colour of which is brown to reddish brown. This formation is virtually impermeable and the plasticity is average to high.

From a hydrogeological perspective, it is not possible to talk of a ground water table in Madrid in the strictest sense of the term. The aquifers are located in the sandiest levels lying in the heart of the clays. The

depth is variable, in view of the alternating and irregular nature of these deposits, and as many as four levels saturated with water flow and water content have been detected.

Construction Processes

For line tunnel between walls, all the services throughout the length of the section have been diverted to allow the walls to be constructed. Excavation work is performed as far as the lower face of the tunnel roof, which is constructed by embedding it into the walls. The excavation is then backfilled with earth over the cast roof and to street level, and the pavement is then replaced. The soil in the tunnel is then excavated, until the lower level of the tunnel invert is revealed. The bottom slab is cast on this floor, and the finishing work is then carried out.

For line tunnel excavated in the open, first, the services have to be diverted. A strip of ground approximately 90 m-wide is required to accommodate the works, which include 15 m-wide work roads to each side of the tunnel. One of these roads is for earth works movements, and the other is for transport of construction materials, such as concrete and reinforcement steel. There is also a 10 m-wide construction road at the top of the slope for traffic through the site.

Points of Access

The excavation comprises a large trench that is approximately 20 m-deep, and 50 m-wide at the top of the cutting. Any potential problems in gaining access to the bottom of the excavation were overcome by preparing three types of access.

Firstly, a permanent access to enable materials to be brought in, which is to be created running roughly crossways to the tunnel layout, making use of the zone that will be taken up by the emergency exit. This access point was prepared with a concrete surface together with necessary drains, ditches and kerbs, to ensure that access can be gained in all types of weather. This access point overlooks 500 m of the tunnel, and the Fuenlabrada 2 station on one side, and the rest of the layout in the opposite direction. An attempt will be made to create another access point at the emergency exit situated at km 1+600, with a view to reducing the length of the access to the work site, depending on the room available.

Secondly, an access point for extracting the spoil, which under normal circumstances is located in front of the excavation, through which the entry of materials is not permitted, because this would obstruct the work being carried out on the inverted vault, where there is a 90 cm step.



Gantry placing prefabricated roof reinforcement.

Thirdly, an access point at the end of the excavation. This has extra width throughout the length of the ramp so that spoil can be removed from the end of the excavation zone. As this type of access point is not provided with a surface area that is large enough for it to be constructed crossways, the excavation levels depend on the length of the ramp. The excavation zone is to be longer than normal, to avoid a greater amount of intermediate stockpiling, with the associated negative environmental impact.

The inverted vault for the section is V-shaped. The back diggers that are to be used for the excavation works cannot be used to achieve the correct alignments, because the restricted width at the bottom of the excavation means that it will not be possible to use them crossways. Back diggers are to be used that can excavate from the side, because these vehicles are equipped with a carrying device for this purpose. This type of machine generally has a lower capacity, which makes the activity more laborious than is desirable, given that the task to be excavated is particularly hard.

Access will be gained for the filling activities via the fixed ramp until the area at the back of the sidewalls has been filled up. Then ramps will be constructed running parallel to the slope, along similar lines to the access ramp at the bottom of the excavation.

Shuttered Concreting

Once the bottom of the excavation has been trued up or aligned, the cleaning concrete is laid, and the formwork and shuttering is prepared for the inverted vault, and the reinforcement installed, followed by concreting.

The sidewalls are built separately from the roof, with a view to making construction



Pouring concrete into the formworks.

easier. If the roof were to be concreted at the same time as the side walls, it would be difficult to install the reinforcements, and the volumes of concrete involved would be as much as 200 m³. A suitable rate for laying concrete in this type of construction is 35 to 40 m³/h. Laying concrete at rates exceeding 100 to 120 m³/h would involve a risk of reduced quality, not least because the personnel involved would be tired when performing repetitive work, day after day.

To prevent any potential stoppages due to the mobile crane not being able to enter the site to move the formwork panelling, pre-assembly of the reinforcement has been undertaken. This allows it to be moved by specially-equipped trucks.

The roof is constructed with the aid of two units of metallic formwork, which are transported on a specially-designed gantry. This runs on a rail and hydraulic racking device, so that it can be located at the back of the sidewalls, inside the module to be concreted. This gantry will allow lorries to pass through to transport reinforcement, concrete, and other material. The formwork has been designed in such a way that it will be possible to lay the concrete without using the gantry as a support. This allows the second unit of formwork to be repositioned while the first unit is being concreted.

The geometry of the roof, which has a double radius, and an almost vertical zone running on from the sidewalls, makes it very difficult to place reinforcement *in-situ*. A prefabrication technique is being employed, using roof frames that have exactly the same geometrical characteristics as the upper and lower vaults. As the only room available is the zone inside the tunnel itself, it will obstruct movement inside the tunnel while it is being erected, impeding the entry of materials for the inverted vault and sidewall work areas.

These reinforcement panels are positioned with the aid of a portico that moves

along the exterior of the tunnel, and this device is equipped with four hoisting blocks. This portico is also used to position the formwork, which has been provided with windows to allow for the right degree of vibration.

The two units of formwork are put in place alternately, so that they can both be worked on at the same time. With this in mind, the first unit of formwork will be provided with two taping devices for the concrete. These also support the water-stop type joint that is located between modules. The second unit of formwork lies against the two roofs that have already been concreted. If the two units of formwork are located correctly, this method ensures that there is no interference caused between the reinforcement and the taping devices, and the length of the open section of excavation is reduced to a minimum.

Because the minimum radius of the layout is 300 m, there is a difference in length in each module of up to 30 cm between the inner and outer sidewalls. To counter this, a series of 25 cm-long sliding metal strips have been designed for the ends of the formwork. These telescope, in order to adjust the formworks to each bend along the section.

Station

The station will comprise an area enclosed by the walls, and is being constructed by cut and cover. The outer walls were installed and topped, and then the roofing slab was constructed. When this slab was finished, it was waterproofed and the surface reinstated. Excavation beneath the slab was then undertaken to the flooring, or bracing, level, and then on downwards, beneath the flooring to the invert elevation.

Prefabricated reinforced concrete pillars are installed as the intermediate supports for the station, and these have been founded upon piles that were concreted *in-situ*. The pillars were installed from the surface, before the roofing slab was cast. The following construction sequence was used: drilling for the pile; installing pile reinforcements; putting the pillar in place; concreting the pile; packing hollow sand around the pillar. **13**

Main Quantities

Length of the section	1,867.75 m
Tunnel between walls	335.00 m
Tunnel in the open	1,400.00 m
Number of stations	1 unit
Excavation	905.054 m ³
Embankment	637.978 m ³
Concrete	83.338 m ³
Steel for reinforcement	6,873,718 kg
Walls	21,529 m ³

Contract 4 Subsections IIIB/IVA

Contractor: **Sacyr**



Connecting Loranca in Fuenlabrada District

Contract IV, sub-segments IIIB and IVA of Metrosur were awarded to Sacyr S.A. in April, 2000, and are situated in Loranca, in the district of Fuenlabrada. The budget is Pta5,371 million, with an expected duration of 18 months. The contract includes civil work, rail-laying and station architecture, and is 821 m long, of which 413.13 m are being excavated using the traditional Madrid method, 275.17 m are being excavated between supporting walls, and 133 m are station. The route follows the main streets and avenues, and the station is located in the heart of the urban area, next to the municipal building, the Cultural Centre, a school, and a new Health Centre which is still under construction.

Project Description

The route of segment IIIB starts 275.17m before the entrance to Fuenlabrada 1 station in Loranca. Between km 0+0.00 and km 0+0.275.17, the tunnel runs below Alegría Street, and is formed by retaining walls covered with an *in-situ* slab. The station is situated between km 0+0.275.17 and km 0+406.87, next to the District Council Buildings. The average depth of the station relative to the track varies between 13.8 m and 16.8 m. An electricity substation is incorporated into the design.

Subsegment IVA runs from km 0+406.87 to km 0+820.00 where the local football ground is located, and a 16% gradient ramp next to the civil gardens provides access to the tunnel from Alegría Street and Pablo Iglesias Street. The section is 114 m-long, of which 73 m run straight and 41 m are curved, with a radius of 150 m. The curved section was built using the traditional Madrid method, once there was more than 8 m of cover. The point



where the ramp meets the tunnel is formed using supported arches.

The ramp provides access to the tunnel, and once the tunnel reached the station, it facilitated the clearing of the station as well. The tunnel also provides access to the station for materials and finishes, as well as for tracklaying. Once the contract is completed, this ramp will be closed and filled to where it joins the tunnel.

From km 0+406.87 the tunnel runs straight, following Alegría Street, and at the end of this street it turns south in a curve with a 300 m radius. Between km 0+620 and km 0+710 the tunnel passes

Looking back from the face of the top heading.



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beneath the Fregacedos School sports ground, and from there runs under Gabriela Mistral until it reaches the Municipal football ground at Loranca.

The track superstructure is a 54 kg/m rail, which is laid on reinforced concrete blocks which are covered on both sides by a Corkelas type elastomer made by Edilón, and fixed by the Pandrol clip system. The blocks are designed support a 12.5 t axle load.

Plans are for two types of rail switching at either side of the station consisting of 0.125 TG crossings, 7.90 m elastic points and 10.523 m points, supported by a set of pre-fabricated concrete blocks and shims with Corkelas type elastomers between blocks and shims. Pandrol clips fix the crossings and adjacent tracks. The crossing comes with four rail posts pre-welded under pressure.

Methodology

The whole of the section IIIB tunnel was constructed with retaining walls. Each wall is 0.8 m-thick. Tunnel width is 8.2 m covered by a 0.8 m-thick slab with 0.9 m supports.

The entire sub-segment IVA was excavated using the traditional Madrid method, 8.2 m-high and 7.8 m-wide. It begins with an excavated gallery, which is then progressively cleared to form the upper part of the section. An average advance of 2.5 m/day was achieved.

From the geotechnical point of view, the main worries with this project are subsidence and settlement, which can affect existing buildings or structures close to the route of the tunnel.

Thankfully, due to both the route of the project running beneath existing roads, and the types of construction used, possible adverse effects are minimal.

As part of the Metrosur project, a complete geotechnical, geological, and hydrological analysis was carried out, and the best method of construction was chosen. This study included identification of the quickest remedies for all foreseeable problems, such as lack of cohesion, slides or water ingress. The soil encountered is predominantly tosca arenosa, a weak sand-stone with limited standup time.

A comprehensive series of tests and controls is used to check and detect the least movement in soil, buildings and structures, and to ensure that any such movement remains within acceptable limits, both during and after the construction work.

Tunnel Construction

For tunnel sub-section IIIB the construction sequence was as follows: first of all, existing services along the route were re-routed;



then the horizontal work platform was prepared, from which first the guides, and then the retaining walls, were sunk; then excavation commenced to the level of the underside of the roof slab. Concrete was then poured to form the slab on top of the walls and the ground. The soil was in-filled up to street level, and the asphalt relaid to

Traditionally mined top heading under preparation.

Traditionally mined curved tunnel.



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PROJECTS

- ELECTRICAL AND MECHANICAL INSTALLATIONS, RAILWAY INTERCHANGES OF MADRID. LINE MADRID-MÓSTOLES. SECTION: ATOCHA-EMBAJADORES.
- MADRID METRO. NEW DESIGN FOR LINE 10. SECTION: PLAZA DE ESPAÑA-LAGO, 2,0 KM. LONG TUNNEL.
- INFRASTRUCTURE OF THE EXTENSION OF MADRID METRO. LINE 1 TO VALLECAS - VILLA, THREE UNDERGROUND STATIONS. 2,5 KM. LONG TUNNEL AND AN INTEGRATED METRO AND BUS TRANSPORT CENTRE.
- CONSTRUCTION PROJECT. SECTION: BARAJAS - NEW TERMINALS. LINE 8. MADRID METRO.
- CONSTRUCTION PROJECT FOR THE INFRASTRUCTURE OF THE SECOND SECTION OF METROSUR: MOSTOLES 1 STATION - MOSTOLES 4 SATATION.
- CONSTRUCTION PROJECT FOR THE INFRASTRUCTURE OF METROSUR. SECTION 4: FUENLABRADA 1 STATION-FUENLABRADA 4.

SUPERVISION

- INFRASTRUCTURE WORKS FOR METROSUR. SECTION 3: MOSTOLES 4 STATION-KM. 11+582

QUALITY CONTROL

- TECHNICAL ASSISTANCE TO QUALITY CONTROL OF THE WORKS; EXTENSION OF LINE 7 OF MADRID METRO. SECTION: GUZMAN EL BUENO-VIRGEN DE LA PALOMA.
- COMMUNICATION CORRIDORS FOR PASSENGERS BETWEEN LINE 5 OF MADRID METRO AND THE PASILLO VERDE FERROVIARIO RAILWAY LINE IN PIRAMIDES STATION.
- TECHNICAL ASSISTANCE FOR THE SUPERVISION OF RAILWAY BURYING WORKS IN GETAFE.
- COVERING OF AN STATION IN RIVAS - VACIAMADRID (EXTENSION OF LINE 9).
- INFRASTRUCTURE WORKS FOR METROSUR. SECTION 3: MOSTOLES 4 STATION - KM. 11+582



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METROSUR, WORK WELL DONE

We have been collaborating in the Madrid METRO's development since we were set up 36 years ago. We have provided technical assistance throughout this time to a large part of the Madrid Regional Government's underground (metropolitan) network, using state-of-the-art technology. The most recent undertakings relating to METROSUR are the following:

Construction design of Metrosur's stretch I and line 10's new carriage sheds.

Technical assistance for constructing Metrosur's stretches III-b, IV-a and IV-b.

Intecsa-Inarsa plans all types of infrastructures in a complete, interdisciplinary fashion, particularly for railway transportation, both intercity and metropolitan (underground). Activities range from drawing up feasibility studies involving the planning of each phase up to construction supervision and management.



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facilitate renewed traffic flow, as early as possible.

Once the above-ground slab was laid, the tracks, installations and finishes could begin.

The traditional method of tunnel construction, used in Madrid since the 1920s, was applied to sub-segment IVA in successive phases according to the following sequence.

Using pneumatic drills, a 1 m-wide by 2.5 m-long gallery was opened at roof level in the axis of the tunnel, supported initially with boards, and then with longitudinal beams at 1.0 m separation, supported by 1.5 m to 2.5 m-high timber props to pin the boards to the crown. Once this gallery is formed, the excavation is widened using pairs of boards and beams. To excavate a twin track metro tunnel of 8.2 m x 7.8 m, four separate compartments are used.

Once the roof excavation is complete, it is concreted to between 0.8-0.9 m-thick using HEB 140s with the size and shape of the interior of the tunnel. To minimise the deformation of the ground, concrete is pumped at 20 Nm and transmits the weight to the roof almost immediately.

Once finished, mechanical excavation can be used down the middle of the tunnel, with the face of the excavation some 15 m beyond the limit of the last ring, but leaving 1.5 m at either side to guarantee the transfer of weight from the roof to the floor. This ground is later removed in 2.5 m-wide panels, alternating from one side of the tunnel to the other. These places are propped by hand, then shuttered with metal, and 0.9 m-deep concrete is poured. Finally mortar is injected at low pressure to fill all possible gaps and small holes.

This method has many obvious benefits, including the stability of the tunnel face, accurate control, minimised deformation of terrain, and tunnel support immediately after excavation. It is adaptable to almost any type of terrain, and is versatile in the



event of unexpected problems. It is also sufficiently flexible to accommodate variations in mid-excavation, such as changes of width, shuttering, or excavation face advance.

Downsides include slow forward progress of 12.5 m to 15.0 m per week, coupled with the need for specialised trades, which are increasingly scarce.

The ramp for access to the tunnel was constructed mainly by the traditional

Excavating sidewalls of traditional tunnel.

PRINCIPAL STATISTICS

m ³ retaining walls and piles	14,414
m ³ Traditional Madrid Method excavation	33,247
m ³ excavated material	78,041
Kg reinforcement	3,471,822
m ³ Concrete	49,986
Linear metres, tunnel between retaining walls	275
Linear metres, Traditional Madrid Method tunnel	454
Linear metres, Station	133
Linear metres, Track	3,280
Budget sub-segment III B	3,341,277,490 pts
Budget sub-segment IV A	2,029,685,350 pts
Construction Period	15 months



Concrete cover of Fuenlabrada 1 station.

Mezzanine floor at Fuenlabrada 1 station.



material from the station, and from the areas of tunnel excavated between retaining walls. The ramp access is also a useful delivery route for finishing materials and track installation.

Fuenlabrada 1 Station

This station is right in the middle of the borough of Fuenlabrada, in which the only noticeable change after completion will be the entry and exit points. It has been placed in line with two streets, Alegría Street and Libertad Street, which means the exits are in a square in front of the new District Council Buildings, on a plot destined for commercial use.

The structure uses pre-cast beams and slabs spanning an open plan area 29 m-wide between retaining walls. Access has been kept as simple as possible, using a single intermediate level between streets and platforms, where the ticket gates will be located. From this point, the platforms dominate the view, helping to avoid passenger disorientation and aiding flow by keeping ticket machines perpendicular to the platforms. These platforms are 115 m-long and 5.3 m-wide.

The electricity substation has been incorporated into part of the space above the platforms. This will house eight transformers, each weighing 13 t, in a separately ventilated environment. Access to the substation and cables will be shared with the emergency stairways.

Located between km 0+275.17 and 0+406.11, the station is formed by 0.8 m and 1.0 m-thick concrete retaining walls, using cut and cover. The roof was formed in two different ways: *in-situ* slabs for the ventilation and substation areas; and pre-cast 1.85 m beams over the vestibule. Excavation started once the walls were in place.

The excavation for the walls was carried out in 2.5 m segments of up to -29.60 m. Due to the local soil conditions, and with a water table below the level of the works, the use of bentonite was unnecessary, permitting excavation rates of between 100-140 m²/team/day, and avoiding the environmental problems associated with bentonite residues.

Once the walls were completed, and the guides removed, soil was removed from the inside face of the wall, which was then cleaned and prepared for the pouring of the slab. Once the slab was up to strength, the vestibule area could be excavated to the level of the vestibule floor. Here, the steel in the retaining wall was exposed, to interlock with the rebar of the floor slab. The slab was poured onto the soil, and the excavation process repeated to track level. Another 8 x 1 m-diameter piles support the span of the vestibule slab. 



Contract 4 Sections V & VI

Contractor: **necso**



Mining Beneath Fuenlabrada to Getafe Suburbs

Contract 4 covers sections V and VI of Metrosur, and was awarded to Necso Entrecanales Cubertias in April, 2000. This contract is 6.517 km-long, roughly 5.2 km of which are in Fuenlabrada, and 1.3 km in Getafe. It includes four complete stations, one of which connects to the suburban railway system, together with a fifth station position, prepared for future use. It also includes 12 vertical shafts, of which four are for ventilation, two for pumping, one for ventilation and pumping, and five for emergency exits.

The contract was awarded at a value of Pta 25,103,910,736 with a duration of 30 months from the date of the survey on 24th May, 2000, so the work should be completed by 24th November, 2002.

Tunnel Alignment

The alignment starts at the exit of Fuenlabrada 2 station, which services the King Juan Carlos University. It intersects the M-506 main road, and runs along Calle Francia to Fuenlabrada 3 station. It curves right, and changes to a left curve to reach the existing Fuenlabrada station on the suburban railway system. Here, Fuenlabrada 4 metro station and the corresponding interchange with line C-5 will be located. The alignment continues through old Fuenlabrada district, north of the previous town hall, and follows Calle Miguel de Unamuno. Fuenlabrada 5 station is located where this street joins Avenida de Venezuela. The line then runs along the latter avenue, crosses Avenida de la Hispanidad, and then heads across open country towards Getafe. On its way, it crosses the Culebro gully, which has been diverted as part of the works. The future Fuenlabrada 6 station is located on this stretch.



In the Getafe municipality, the line crosses beneath the M50 ring road to Getafe 1 station, which is located in Sector 3. This part of the line continues through Sector 3, and finishes in Avenida de Arcas de Agua, at the entrance to Getafe 2 station.

The tunnel runs at considerable depth of 20 – 25 m under the developed areas, where the buildings are up to four storeys high.

Geology and Geotechnics

The catchment area, which occupies most of the province, is known as the Cuenca de Madrid, and forms part of the Tagus river basin. It is filled with layers of Tertiary sediments of significant thickness, whose character varies according to the position in the catchment. Three types of facies can

Concreting alternate sections of false tunnel roof.

Metro of Madrid



Metrosur



engineering the future

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- L-7 Section Guzmán el Bueno - Valdezarza
- L-8 Section Recintos FERIALES - Barajas Airport
- L-9 Section Puerta de Arganda - Arganda
- L-10 Section Lago - Príncipe Pío, crossing below Manzanares River
- Metrosur Sections II - V and XII

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be readily distinguished: the Madrid facies, consisting of arkosic sand of varying grain size and grey-brown or brown clay, locally identified with coarse sand and hardpan; the Intermedia facies, consisting of highly-plastic brown and green clay, or peñuelas, with intermittent layers of micaceous sand; and the Central facies, which is of a chemical nature, consisting of chalk and chalky marl.

This section is entirely located in areas of hardpan and sandy soils associated with the Madrid facies. One of the main characteristics of these materials is the structure. They cannot be classified as different strata, but appear as a group of lenticular deposits of differing lateral continuity which overlap, and alternate with, sandy and clayey deposits. This makes it difficult to correlate their position at different points.

On this section, the clayey soils predominate over the sandy layers, although in some areas, the latter are present in considerable thickness. The main features of this section are, first, the hardpan or sediments with high plasticity and properties similar to peñuela green clay, with an appearance of smooth areas, high plasticity and traces of sepiolite, especially at the end of the section. Secondly, important thicknesses of poorly-compacted sandy soil corresponding to the feldspathic sandy inclines appear at higher levels.

Quaternary alluvial deposits overlie the Tertiary material in the bottom of valleys, accompanied by anthropic fill, usually of little thickness, in urban areas and their surroundings.

The land affected by the project is upper/lower Quaternary in nature, except for the Quaternary soils, comprising anthropic fill, compacted fill and alluvial deposits, which have been identified locally on some sections of the alignment.

The lithological features are as follows: Quaternary: compacted deposits; uncompacted anthropic fill; alluvial. Upper/lower Quaternary: coarse sand; hardpan sands; sandy hardpan; hardpan; sepiolite; chalk.

Contract Components

The contract can be divided into three clearly different parts – in kilometre order.



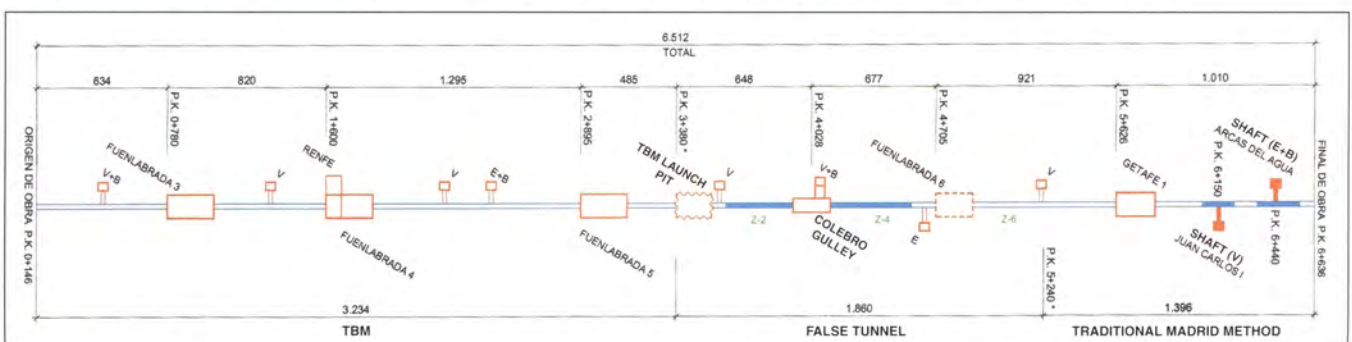
Freight train crosses boxjack section.

The initial 3.2 km, between the new hospital and the by-pass, are located more than 20 m below the surface, under the Fuenlabrada town centre. This will be excavated using an EPB TBM, the safest method, with total support of the soil, including at the face. Settlement will be minimised. This section contains three stations, F3, F4 and F5, and four vertical shafts.

The machine was introduced outside the urban area, close to the by-pass, using a ramp, and access is good. It is working from west to east, and will be removed near F2, in the area of the hospital.

The next following section, up to the M50 ring road, runs through open land, and the tunnel is being excavated in open cut. This section crosses the Culebro gully, which has been diverted. It also includes the future F6 station, of which only the hall will be constructed. This

Schematic layout of Contract 4 tunnel, stations and shafts (V = ventilation, B = pumping, E = emergency).





Construction of future station roof.

station will be completed when the area is developed.

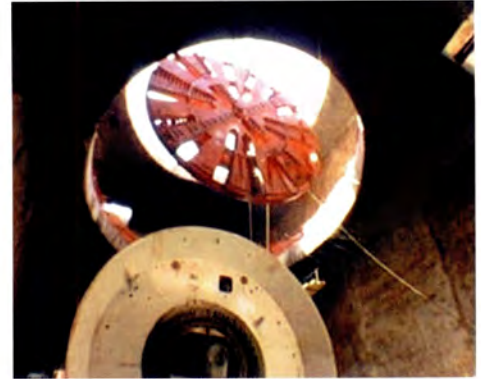
Lastly, from the M50 to the end of the contract, a distance of 1.4 km, the tunnel is being constructed using the traditional Madrid method. This part contains the G1 station and two shafts.

The contract planning was based on the following outputs:

Tunnel with tunnelling machine	350 m/mth
Common Madrid tunnel (per face)	40 m/mth
Open cut tunnel	100 m/month
Cut-off walls (per team)	80 m ² /day
Tunnel section driving	1 mth
Superstructure	700 m/mth

Stations

The design criteria for the stations are based on the organisation of space. The idea is to create a sense of order, where the user has a physical reference, which helps



Lowering the cutterhead of the Herrenknecht TBM.

him or her to relate to the otherwise dark, underground world, where his or her sense of direction tends to evaporate. The chosen finishes and lighting are also aimed at achieving this goal.

The entrances consist of glass pavilions with stainless steel frames, which house the stairs and the escalators. These pavilions, and the corresponding lifts for the handicapped, will receive special attention in the quest for a Metrosur corporate image, creating a reference point on the surface.

Any solution will pursue transparency as a fundamental idea, to avoid the passenger reaching street level visionless. These are particularly significant elements in the urban landscape, so a search was made for a design which would have a low impact.

F4 includes the interchange with the C-5 suburban railway. Here, a vestibule will be built under the tracks, with access to the platforms.

Ground Treatment

The goal of the ground treatment is to prevent excessive settlement in sensitive areas, mainly near buildings. This section of the project contains five micropile cut-off walls, three grout curtains, and three operations to compensate for settlement. This is apart from various fencing, pipe support work,

Section of EPB TBM.



special detection equipment and side slope stabilisation. Except for the side slope stabilisation, which is associated with the section in open cut, all of this work is located in the Fuenlabrada town area.

The detection equipment will provide information on movement and on the water table, and other data which help to monitor the behaviour of the structures, and any possible deviation from the anticipated parameters.

This equipment basically consists of levelling benchmarks on the surface, gauges on buildings, convergence marks in tunnels, strain gauges on the tensile reinforcement of two sections at each station, ceramic pressure sensors where water is expected, and pressure cells in the roof and floor.

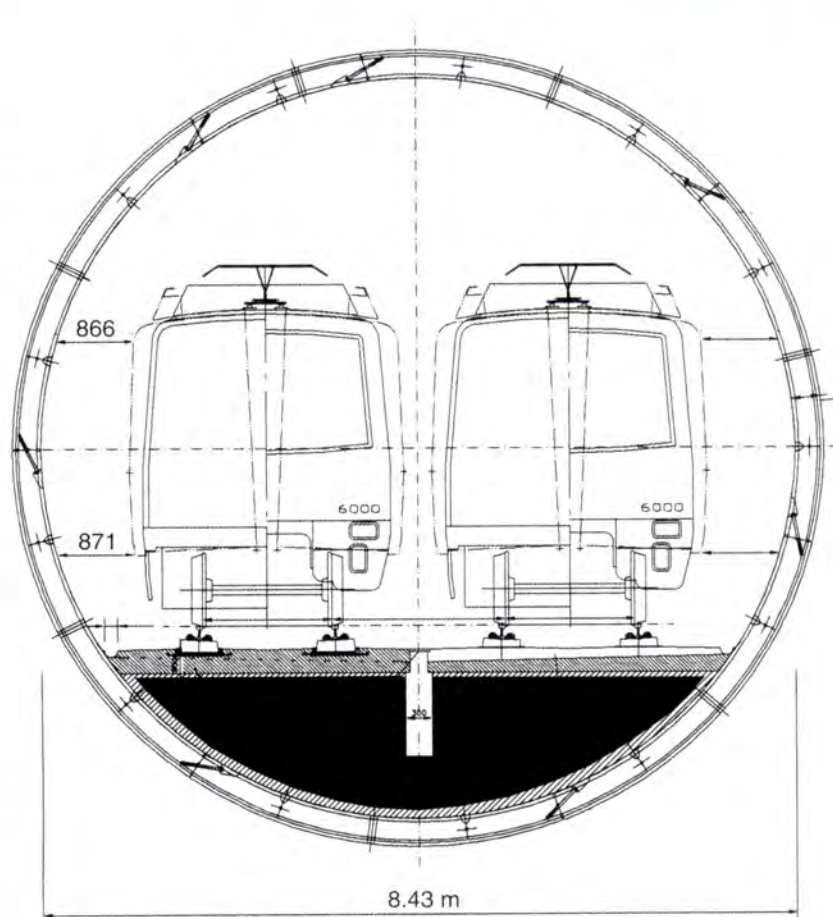
These devices are fitted to all buildings affected by the construction, at all the stations, and to the tunnel cross-section at approximately 400 m-centres.

Construction Methodology

The cross-section of the driven tunnel is circular, with an 8.43 m clear diameter and 9.07 m external diameter. There are seven liner segments of 0.32 m thickness and 1.50 m in length per ring.

The tunnelling machine is called La Paloma, made by Herrenknecht. It can work in a closed environment, controlling the pressure at the face to prevent decompression of the soil, and avoid settlement of buildings on the surface.

The cutting wheel loosens the soil using rotating teeth and discs, and mixes it with foam to make it easier to handle. Soil is removed from the pressure chamber via a worm screw, which discharges onto a belt. This in turn discharges into locomotive-hauled muck cars, running on tracks to the portal, where the spoil is tipped into a pit. It is later reloaded and taken to the tip by truck.



Lining segments are produced off-site by the carousel method, are steam-cured, and their quality is strictly controlled.

Standard TBM section for twin track tunnel.

For the open cut section, an excavation was first made from the TBM launch pit in the opposite direction, towards Getafe. The open cut tunnel is constructed according to the following steps: floor slab; haunches using traditional formwork; roof using mobile formwork. After construction is complete, the excavation is back-filled, and the surface restored. The total volume of excavation is 1,300,000 m³.

The main features of the tunnelling machine are:

	SPECIFICATION	REMARKS
Type, model or series	EPB / OPEN MODE	Herrenknecht
Excavation diameter (mm)	9360	With new tools
Total power (kW)	3250	
Total length (mm)	8025	+ 725 mm cutting wheel
Minimum radius of curvature (m)	250	
Articulations (no.)	1	
Back-up length (mm)	57,000	Depends on feed train
Total weight/TBM & back-up (t)	1350	
Cutting tools (no.)	150	
Gauging tools (no./mm)	3/10-20-30-40	hydraulic/mechanical
rpm	4.1	
Pushing force (t)	10,000	
Travel (mm)	2000	

*Traditional Madrid method of excavation.**Spoil conveyor from top heading face.*

The principal quantities of the contract are as follows:

TBM tunnel	3,300 m
False tunnel	1,750 m
Traditional Madrid tunnel	1,325 m
Liner segments	14,000 u
Excavation	2,000,000 m ³
Fill	1,350,000 m ³
Total length – soil treatment	4,700 m
Consolidation grouting	2,800 m ³
Cut-off walls	65,000 m ³
Piles	1,600 m ³
Precast columns	1,700 m
Concrete	205,000 m ³
Steel bars	17,700 t
Rolled steel sections	380 t
Rail	26,100 m
Elastic spikes	31,000 u
Cement gravel track bed	53,000 m ³
Cladding panels	11,000 m ²

Traditional Method

The final section will be constructed using the Madrid method. This method is traditional and requires considerable workmanship. The cross-section is similar to cut and cover, but it is constructed in three steps: arch, haunches and floor slab.

The arch construction is the most complex, and the most important. It is in turn divided into two parts: the pilot gallery, which is an excavation 2 m-high and 1 m-wide, using props, longitudinal bearers and boards; and the widening, totally propped, using the same methods, until the upper third of the cross-section that forms the curved roof is exposed. This is then concreted, using a pump from the outside, while maintaining the shuttering in position. The central part of the bench is excavated, and then the haunches are excavated in intermittent vertical sections, staggered with regard to the arch, so it is always supported. The floor slab is constructed in lengths of 20 m.

Stations

The cut and cover procedure was used for stations F3, F4 and F5. This consists of the following construction sequence: cut-off walls; roof slab; excavation down to vestibule level; the vestibule; excavation down to the metro roof level; metro roof; and platforms and finishes.

Stations F6 and G1 are the deepest, and they are covered with an arch, which has a 17 m span. This type of arch covers half of G1, and completely covers F6. The arch



View through the box jacked section.

was concreted on the ground in the case of G1. At F6, where there are pillars at 5 m centres, mobile prefabricated formwork was used.

Jacking Under Railway Lines

At the Fuenlabrada 4 station, there will be an interchange with the suburban railway system, consisting of a 40 m x 20 m reinforced concrete vestibule. This structure was fabricated in one part of the Metrosur station, and then jacked under the five existing suburban lines.

This box construction and jacking sequence is as follows. First, the displacement bed is prepared and the thrusting base constructed. Then the box structure, consisting of a rectangular cross-section with two cells separated by a line of columns, is constructed. The attack face has two triangular sections in cantilever, extending the haunches, to provide soil support during the jacking process.

Longitudinal propping of the tracks is undertaken, by groups of rails placed either side of each rail in use, and notched below to take a length of rail at right angles to the tracks. This length is suspended from the first groups of rails, using special brackets. These supports rest perpendicularly on the soldier beams (RSJ sections), which in turn are supported by the rear of the structure. The far end rests on the soil.



Arched station roof under construction.

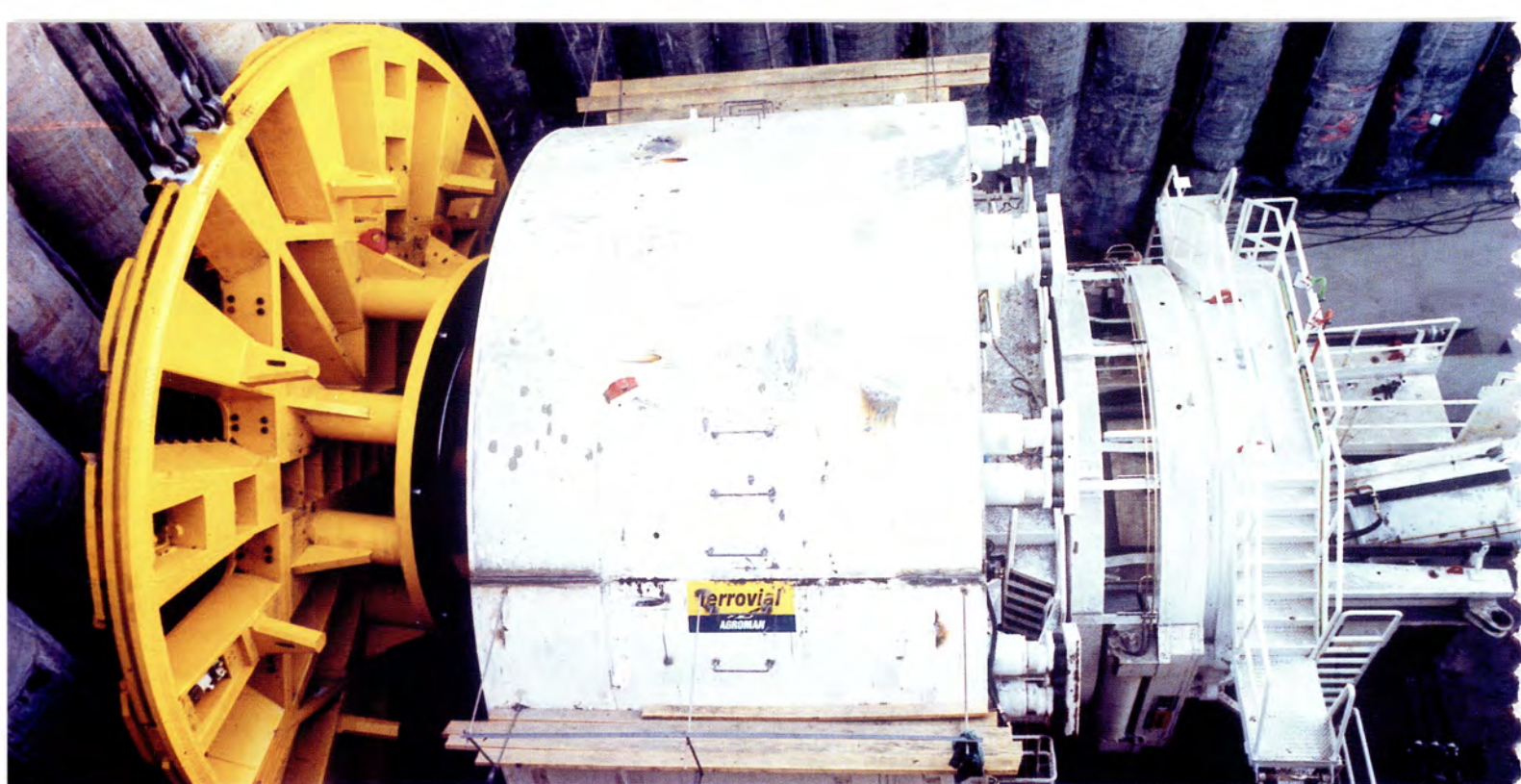
Movement of the box structure is achieved through the thrust provided by jacks reacting on the thrust base. Prior to each jacking cycle, the soil is excavated using conventional means from inside the structure. This is followed by removal of propping, and restitution of the tracks, following which the auxiliary construction is demolished.

By mid-July, 2001 some 45% of the contract time had expired and progress was as follows:

stations: concrete 85%, excavation 65%; vertical shafts 70%; ground treatment 50%; open cut tunnel 70%; traditional 40%; TBM under launch. **T B**

Box jacking arrangement to cross beneath Renfe tracks.





We're making **Metro kilometres**

Throughout Ferrovial Agroman's history we have built a total of 66,51 kilometres of underground railways. Having completed the 6,35-kilometre extension of lines 1 and 7, we have now taken on a new project: the extension of Madrid's Metrosur Tramo Getafe, Gálibo Line 10 and Nuevos Ministerios - Mar de Cristal. And, once again, we're using cutting edge technology, both with the Madrid Traditional Method, together with the



necessary ground treatments such as compensation injection and jet-grouting, as well as with the new EPB Mares del Sur tunnel-boring machine with a watertight bulkhead designed to withstand an operative pressure of 3 bars and featuring a cutting wheel with a diameter of 9.330 mm. This is how we are moving forward, metre by metre, forging a total of 14,5 kilometres of new underground railway for all of Madrid's residents.

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Contract 5

Contractor:



Tunnelling Beneath Getafe Town



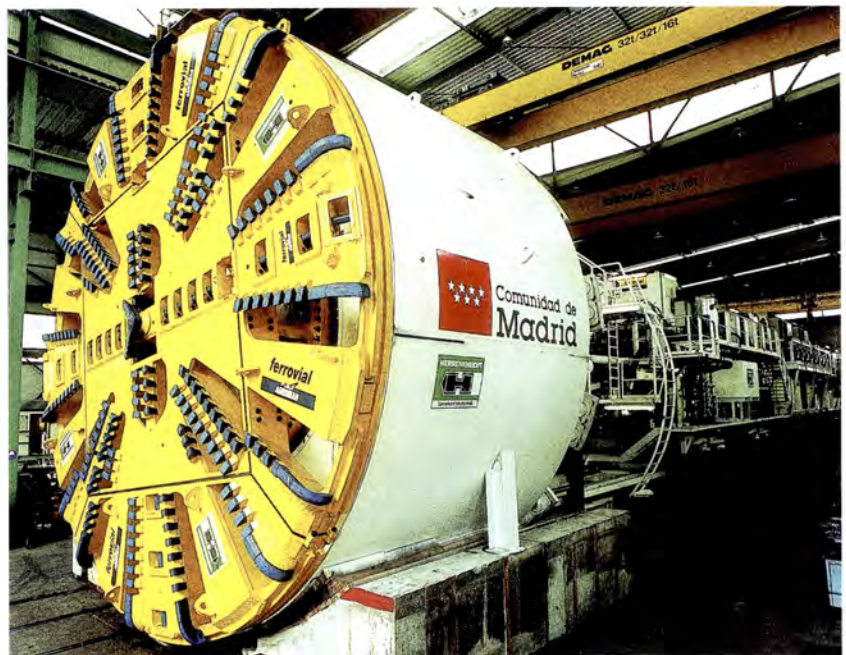
Contract 5 of Metrosur is located entirely within the municipal district of Getafe, and comprises 7.36 km of tunnel, including six stations, ventilation structures, emergency exits, drainage system, track installation, and tunnel lighting with service specifications. It also involves replacement of services and restoration of places where the project might affect the environment.

The whole section is underground, bored by EPB TBM, leaving a tunnel with an inside diameter of 8.43 m. The award budget for the works is Pta26,636 million, with an average cost of Pta2,278 million/km of tunnel, and Pta2,196 million/station.

EPB Tunnelling Machine

In this type of ground, composed of soils and soft rocks, the tunnel is being driven by means of a Herrenknecht EPB shield tunnelling machine, which applies pressure at the face and keeps the excavated soils under pressure. Its main function is to guarantee the stability of the face of the tunnel, and the section where the construction stages are being carried out, thereby assuring minimal surface subsidence.

The tunnel diameter is determined by the operational requirements of the Metro, which requires an inside diameter of 8.43 m. This is obtained with an excavation diameter of 9.38 m using the Madrid



type lining of 32 cm-thick reinforced concrete segments.

The Metrosur Contract 5 TBM Mares del Sur was purchased new for this project, and possesses the latest advances in this type of machine. It has total automation, a laser guidance system, and automatic remote data transmission to the site office. The machine has a mixed cutting head with discs for rock cutting, and is expected to achieve an average advance of 15 rings/day. This equates to a forward movement of 22.5 m/day, with peaks close to 22 rings/day, or 33 m/day.

Herrenknecht 9.38 m EPB TBM for Ferrovial Agroman at Metrosur.



Launch pit for Herrenknecht EPB at El Bercial.

It is an EPB earth pressure shield with a watertight screen designed for an operating pressure of 3 bar. It comprises a cutting head, shield middle body, and tailskin. Its weight is 454 t. A base segment is installed at the bottom of the ring, on which the construction railway track is built.

The tunnelling machine specification is described briefly below.

Propulsion cylinders	13 pairs (26 cylinders) with 320 mm piston diameter, total thrust force 10,000 t, forward speed 0-80 mm/min.
Cutting tools	Cutting wheel with 196 teeth, 16 peripheral rakes, 21 17-inch double discs and 2 copy cutters, which also perforate rock.
Cutting wheel drive	0-3 rpm. Torque 20,236 kNm. Initial starting torque 24,000 kNm, with two directions of rotation. Installed capacity 2.800 kW. 17 Rollstar G269 hydraulic gear motors. 17 pinions with dual housing. Diameter 5,000 mm.
Electrical system	15 kV voltage supply, installed capacity 4,000 kW, 2 transformers 2,500 kVA each.
Guiding system	Electronic Laser System (ELS) with the active objective installed on the shield liner.
Extraction system	Extending, helical worm conveyor with a travel of 1,500 mm, Outside diameter 1,000 mm, 22 helices 630 mm apart. Conveying capacity 550 m ³ /h, output 400 kW. Conveyor belts 1,200 mm wide with a capacity of 800 m ³ /h.
Mortar injection system	6 pipes for injection between lining and ground (5.64 m ³ approx.). Output 45 kW.

The tunnelling machine launch point is in the area where the Getafe 8 station, also known as El Bercial, will be located. A stocking yard has been built for the segments at this access, and installations for compressed air, mortar plant, and ventilation are also located here. The excavated spoil will be removed from this point. During the third quarter of 2001, when the tunnelling machine will have reached

Getafe 4, the launch point installations will be transferred to this station. The tunnelling machine will then continue on its path until reaching Getafe 2 station, where it will be dismantled and removed.

The tunnel lining is formed of Madrid type rings consisting of seven different trapezoidal segments, six of them occupying $\frac{2}{13}$ of the development, and the frustoconical keystone $\frac{1}{13}$ of the circumference.

The segments are of prefabricated reinforced concrete type, 0.32 m thick, with an average length of 1.5 m, which ranges from 1.459 m to 1.542 m. The rings are joined together by means of 13 equidistant (i.e. 27.692° apart) zinc-plated pin bolts, with two bolts per segment, with the exception of the keystone, which has only one bolt.

The alignment passes through mixed Quaternary and Tertiary strata of the Madrid facies, comprising mainly stone, black clay and chalk of 130-150 kg/sq cm compressive strength. It runs below, or crosses, the water table at all times, with an approximate head over the crown of 14 m.

The track superstructure planned complies with the criteria specified by Metro de Madrid for trains composed of 6000 type cars. It is plate track, with naturally hard 54 kg/m rail, resting on reinforced concrete

blocks covered on their inner and side faces with Corkelast type elastomer. These blocks will have to withstand a load of 12.5 t per axle, and their anchorage with the rail will be Pandrol type.

Stations

Metrosur contract 5 includes six stations: Getafe 2, Getafe 3, Getafe 4, Getafe 5,



Map of Metrosur showing Contract 5 in yellow.

Main project details

Unit		Measurement	Total measurement
Im	Total length	EPB tunnel	6,484
		False tunnel	98
		Station pass length	778
			7,360
Kg	Reinforcement steel	Screens and piles	6,107,544
		Tunnel voussoirs	4,765,467
		Other structural work	7,824,143
			18,697,154
m ³	Excavation	Screen-walls and piles	128,144
		Tunnel	441,934
		Other excavations	446,738
			1,016,816
Im	Piles	11,556	11,556
m ²	Screen-walls	51,210	51,210
m ³	Concrete	Screen-walls and piles	52,727
		Tunnel voussoirs	59,004
		Other concrete work	79,815
			191,546
Im	Rail 54 kg/ml	29,444	29,444
U	Elastic blocks for 12.5 t	32,680	32,680
m ²	Vitrex type panels for covering vertical facings of stations	7,836	7,836
m ²	Italfilm panel for covering vertical facings of stations	6,781	6,781
m ²	Concourse and platform paving	22,081	22,081

Getafe 6 (El Casar) and Getafe 7 (Espartales).

The distribution of all the stations in the section is similar, and they each have an entrance concourse floor and a lower platform floor. They all have one or two street accesses to the concourse, equipped with fixed stairs, a pair of mechanical escalators,

and a lift. They are all provided with one emergency exit and ventilation shafts.

There are two stations that have special features as interchanges offering access both to the Metro and to the suburban train system: El Casar, which interchanges with Renfe C-3 line; and Getafe 4 which interchanges with Renfe C-4 line. In



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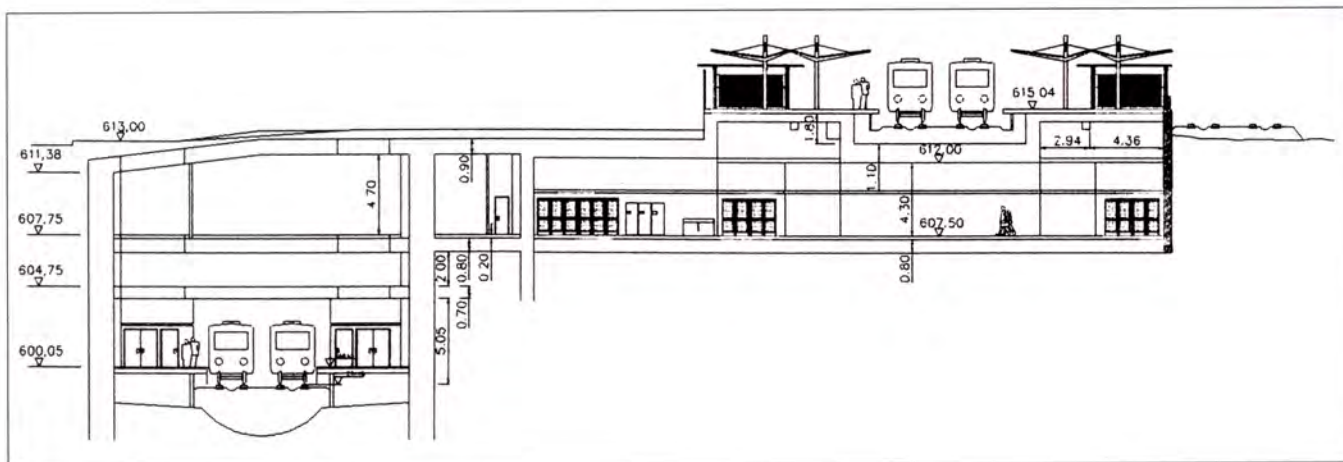
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addition, these stations are equipped with electricity substations.

El Casar station is a shared interchange concourse for access to Renfe (Spanish Railways), for which the station has to line up as closely as possible with the run of the railway line, and with an orientation parallel to it. At an intermediate level between the suburban station and the Metro platform, there is a concourse, which serves as an interchanger between both lines, besides providing access from the outside.

The Getafe-4 station forms part of the Getafe-Suburban complex. The Metrosur track axis lies transversely to the Suburban track axis and at a lower level. The station is designed with a concourse over the tracks at a midway level with respect to the Suburban station platforms. Access to the concourse is gained directly from the Suburban platforms, via two facing stair cores. From the concourse level, access to the platforms is also indirect, by way of two vertical communication cores.

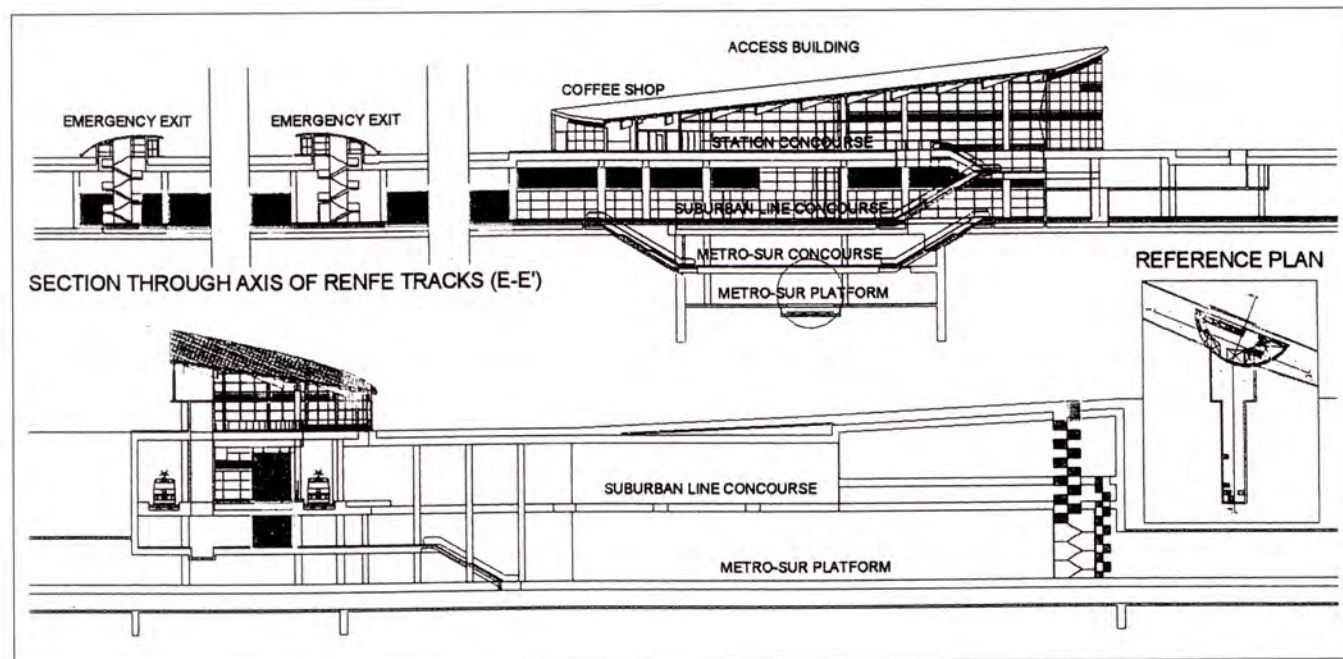
Construction of the stations starts before the tunnelling machine passes through the complex. This offers a number of advantages such as casting the floors against the ground, with the resultant saving on falsework; execution of the roof slab in a short period of time, so that the streets involved may be re-opened for normal use; and saving the tunnelling machine from mining the ground and installing the segmental lining; and saving the costs of demolishing the lining, when excavating the station.

The procedure for carrying out the cut and cover excavations is as follows: installation of the screen-walls; casting *in-situ* of the roof slab; excavation of the concourse level; casting of the concourse level; excavation down to inverted vault level; casting of the inverted vault; and platforms and finishes.

Screen Walls

The screen walls were constructed using different procedures, depending on the type of ground in each case.

Cross-section of Getafe 6 station (El Casar).



Getafe 4 station section.



Hydrocutter at Espartales station.

At Espartales and Getafe 5 stations a hydrocutter was used. This method of excavation is used when the subsoil contains materials such as hard chalks. At Espartales station, about two weeks were

needed to install and assemble the machine, tanks and sludge circuit. Excavation started on 20th July, 2000 on the first screen-wall, while the last one was excavated and concreted eight weeks later, on 14th September. For the primary panels it took around seven hours to complete the three passes needed for excavation; on the secondary panels around three hours were required for the single passage. In total, some 5,000 m³ of earth were excavated in the 49 working days spent on this job.

The system of excavation consists of steadily reducing the size of the material to be excavated, and mixing it with a bentonite suspension. The mixture is then pumped through a system of pipes to a sand removal plant, and may be used until the successive cycles make it unfit.

The bentonite supports the earth wall, and prevents cave-ins. In addition, it does not mix with water, so it does not permit its entry by seepage through the excavated walls.

A complex centrifugal pump, located immediately above the cutting wheels, removes all the excavated material and propels the mixture of soil and bentonite to the plant.

Conventional bucket excavation was used at Getafe 2 station. This method of excavation is used when the subsoil contains such medium resistance earth materials as roughs. The system consists of guiding the bucket by means of cables, which are used for raising, lowering and opening it. The bore bit is used on hard layers of ground. This implement is provided with teeth at the bottom and it is attached to the sides of the bucket for raising and releasing, and in this way breaking up the hard layer so that the earth material may then be removed with the bucket.

Pile drivers with casing were used at El Casar station. This method of excavation is



Detail of hydrocutter head.

used when the subsoil contains such hard earth materials as chalks, but in the upper layers the ground is soft and not very cohesive, with a tendency to crumble. Its main advantage lies in its high performance. To prevent the crumbling of the ground in the first 5 m, casing is installed, with recoverable metal liners. No further shoring is required, once the layer of anthropic waste fill is passed.

Conventional screen with pre-bores was the method used at Getafe 3 and 4 stations. This method of combined excavation is used when the subsoil contains such hard materials as chalks. First, two or three preliminary bores are made with the pile driver to break up the columns of hard earth in each screen module, to assist subsequent excavation with the conventional bucket.

In the particular case of these stations, thixotropic sludge is used, as there is a layer of water-saturated sand in the subsoil. The placement of reinforcement frames, and subsequent concreting, is done by traditional methods.



Roof Slab Construction

Once the screen-wall enclosure is built, the roofing slab is cast on the ground, using

plain formwork consisting of grooved and tongued wooden sheathing.

The roofing slabs for the narrow areas of stations are of reinforced lightweight

Conventional bucket excavation for screen walls at Getafe 2 station.

Performance

Table updated on 11/12/00

	Cased Piles	Hydrocutter	Cased Piles		Hydrocutter	Conven. Screen + Prebores	Conven. Screen
	Implementation shaft	Getafe 7 Espartales	Getafe 6 El Casar		Getafe 5	Getafe 3	Getafe 2
Unit	Piles 1,500	Screens 800	Piles 1,500	Piles 1,000	Screens 800	Screens 1,000	Screen 1,000
Starting date	04/07/00	21/07/00	18/07/00	28/08/00	26/09/00	08/08/00	21/08/00
Completion date	27/07/00	14/09/00	12/09/00	10/10/00 **	30/11/00	17/11/00	27/11/00 *
Nº panels	60	68	156	181	82	82	154
Total measurement	1.393,2 lm	6.150,1 m ²	2.852,1 lm	2.326,0 lm	7.785,5 m ²	7.503,9 m ²	6.796,7 m ²
Total calendar days	23	56	49	39	66	101	98
Total useful days	18	48	39	30	45	46	60
Panels/calendar day	2,6	1,2	3,2	4,6	1,2	0,8	1,6
Panels/useful day	3,3	1,4	4,0	6,0	1,8	1,8	2,5
Measurement/calendar day	60,6	109,8	58,2	59,6	118,0	74,3	69,3
Measurement/useful day	77,4	128,1	73,1	77,5	173,0	163,1	113,3

* Update day. Pending execution of 10 remaining panels (120 m²)

** Pending diversion of RENFE tracks to execute 52 remaining panels



Bore bit for breaking up hard ground.

Concourse and Inverted Vault

In those stations where the tunnelling machine is scheduled to pass immediately, or in the event of it not being able to pass through the space between the inverted vault and the concourse, excavation is carried out down to the level of the inverted vault. Construction can then carry on while waiting for the tunnelling machine to arrive. The concourse slab is then built resting on concrete pillars on the inverted vault, as in the case of Espartales station (Getafe 7).

In those stations where the tunnelling machine is not scheduled to pass immediately and it can pass through the space between the inverted vault and the concourse, excavation is carried out down to concourse level. The floor of the concourse level can then be cast on the ground, and anchored by means of metal ties hanging from the upper slab. Hollowing out is then completed to the inverted vault level, so that this may be built while waiting for the tunnelling machine to pass. This is the case at El Casar (Getafe 6), Getafe 5, Getafe 3 and Getafe 2 stations.

Section lengths with stations

Section	Length	Stations	Accesses	Districts	Zones
VII	1,346 m	Getafe 2	Senda de Mafalda	El Artesón, Cerro de la Herradura	Sector 3
		Getafe 3	El Greco	Fátima, San Isidro, Nuevo Hogar	
VIII	4,022 m	Getafe 4	Calle del Muelle	Casco Antiguo, La Alhóndiga	Getafe Centre
		Getafe 5	Avda. España	Juan de la Cierva, Universidad Carlos III	
IX	1,894 m	El Casar Espartales	Avda. del Casar. Rigoberta Menchu	El Casar Los Espartales, Ventorro Bardalón	Getafe North

construction, so as to reduce their actual weight and edge. This method is used for wide areas of stations, in order to be able to dispense with the pile pillars that would support the floor units, due to their large spans. A more open-plan space is thereby achieved inside the stations. In some cases, this space is not completely free, because metal ties are installed to anchor the concourse hanging from the upper slab. In these situations, concrete pillars are not erected on the inverted vault to support the concourse deck.

Ground Monitoring

For monitoring movements, a system is needed that will provide sufficient knowledge of the way the ground, structures and installation respond to the operations that are being carried out, in order to gauge excavation safety during the execution of the works. All the instruments should be installed before starting excavations, in order to be able to read the movements that take place as the excavation face approaches the site of the instrument.

Contract 6

Contractor:



Serving the Population Centre of Leganés

Contract 6 of Metrosur stretches for 6.99 km through the town of Leganés. It is completely underground, with some 6.11 km in tunnel, and the remaining 780 m forming the stations.

The alignment runs under the principal routes within the town, serving the most populated suburbs and activity centres, such as the Parquesur mall, the bullring "La Cubierta", the Carlos III University, the Severo Ochoa Hospital, and the railway station, which will become a new transport interchange.

There are six stations, each of which is positioned in a travellers zone of radius 500 m. The population in the catchment area of the metro is 115,000, a figure that will rise to 125,000 by 2010. The municipality has 175,000 inhabitants in total, so the metro will provide accessible transport service to 70% of the local population. Leganés 2 station, in the neighbourhood of Zarzquemada, will service 49,000 potential travellers, one of the highest usages in the whole Metrosur system.

The tunnel is under construction at 8.43 m inside diameter using an EPB shield. At Leganés 1 and Leganés 5 stations, electric traction substations will be built. Along the alignment, a total of six ventilation shafts, six pumping shafts, two launch and retrieval shafts for the TBM, and one intermediate shaft for spoil extraction, will be built.

The works include concreting of the invert to support the rail superstructure, and assembly of the rail track, as well as the lighting and power installations for the tunnel and stations.

The budget is Pta29,400 million, and the construction term is 29 months.



Construction

The TBM has 9.38 m external diameter and a length of 11.58 m. It has 26 cylinders with a total maximum thrust of 10,000 t. Its unblocking torque is 2.217 tm.

It was launched from a 200 m-long x 10 m-wide shaft, installed in open fields using pile walls. Later, the shaft will be

Aerial view of TBM launch pit north of Getafe 8 station.

VENTILATION SYSTEMS

Jet and axial fans



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reinstated as a part of the tunnel, with cover of around 6 m. Its length allowed complete assembly of the TBM and its backup, and also accommodates the muck pit, from where the material will be removed with back-hoe and trucks.

The tunnel will be supported and lined using the universal Madrid-type ring of six segments and keystone, with an invert segment fabricated and placed to support the twin track railway. The segments will be handled by a 35 t gantry.

The excavation diameter is 9.38 m, and the segments have a trapezoidal shape suitable for describing the minimum radius of 150 m. Each ring comprises seven segments, of which one is a tapered keystone, and the other six with angle in the centre.

The rings have 9.07 m external diameter, 1.5 m length, and 320 mm of thickness. They are connected together using 13 bolts spaced equidistantly, with two for each segment, and one for the keystone. The annular space between the segments and the soil is injected immediately with dry-mix mortar, in order to reduce the risk of surface subsidence to a minimum. This mortar has low cement and high ash content, to ensure easy pumping.

The TBM cutting head is continuously monitored, and inspected every third day, when any worn or missing tools are replaced. Earlier, two rows of tail brushes were replaced in a delicate operation which involved pulling the TBM tailskin into a completed ring.

The stations are constructed with perimeter walls and concrete roofs, with secure excavation or anchoring of the walls, and concreting of the invert to allow passage of the TBM.

After that event, the structures of the hall, accesses, technical rooms and platforms will be completed.

In order to avoid problems that might provoke collapse under buildings, a subsidence monitoring plan has been developed, as well as a programme of special ground treatment in the zones where it is found to be necessary.

Typical Geology

The soils along the alignment of the new line are very typical of Madrid. Until leaving El Bercial station, the route passes through colluvial-alluvial soils, micaceous sand and miocenico peñuelas. From there on, the TBM encounters highly compact sandy clays.

The upper part of the tunnel will be excavated in tosco sands and tosco, with the invert in sands in the beginning, through micaceous sands later, and in peñuela in the final stretch. TBM boring



will be affected by the heterogeneity of the cut.

NFM TBM La Chata under launch at Leganés.

Although the water table will be permanently around level 615, high pressures are not expected. Apart from the water table, there are water pockets of different sizes overlying watertight strata, which could drain the sand where they lie.

Inserting a station support column into a predrilled hole.





TBM breakthrough into a half-constructed station.

Pouring the concrete roof of a station box.

The project includes a budget of about \$2 million for ground monitoring, and for the control of ground movement and subsidence along the route. Along the alignment of the tunnel, there will be a levelling point every 50 m, and a profile with extensometers and eight levelling points in

the most sensitive areas. Levelling points will be placed in the façades of all buildings in the vicinity of the works.

In the stations, four instrumented profiles will be set up in the concrete diaphragm walls, each with four pressure cells, inclinometers and extensometers.

The tunnel lining will be constantly watched through instrumented segments, with pressure cells and extensometers, and regular control of the geometric deformation of the section with convergence nails.

Besides these measures, before the TBM tunnel construction commenced, several treatments of the subsoil were undertaken in order to avoid settlements or collapses on surface.

To determine the countermeasures, a study was carried out to define the possible movements of all the buildings located within one tunnel-depth laterally of the alignment. To facilitate this study, all available data about the buildings were collected, such as year of construction, nature and depth of foundations, type of structure, floor and basement area, and the existence of cracks. Collector sewers, large diameter water pipes, high-tension towers and old wells were all inspected and mapped. In addition, an extensive campaign of geotechnical tests was carried out in all the potential problem areas.

At all points where the tunnel was excavated with less than one diameter of cover, and in less consolidated alluvial soils like those found in Leganés, it was necessary to carry out several high pressure jet grouted injections of cement to consolidate the ground. Under problematic buildings, the injection was carried out through screwed, orificed steel pipes, in order to have better control of the pressure and cement admission, and to avoid lifting the structure. In one case, because of lack of space, injections were carried out from a pile well.

Finally, some work was required to seek out old wells along the alignment, and fill them with mortar, as a safety measure above the TBM.

The TBM has already driven successfully under several buildings and an underground car park some 180 m-long, and with just 5 m clearance.

Progress

At the time of writing in July, 2001 the TBM had bored 5,538 m at an average of 19 m/day.

Since its launch on 5th October, 2000, some 281 days earlier, both the total advance and the average rate were the highest of all the TBMs currently involved in Metrosur.

The TBM is now in Leganés 5 station, and preparing for the last 950 m of tunnel to the final shaft.



Major Quantities

Length of the alignment	6,990 m
Tunnel with EPB	6,068 m
Open-cut tunnel	142 m
Number of stations	6
Excavation	1,100,000 cu m
Concrete	310,000 cu m
Steel	24,000,000 kg
Walls	60,000 sq m

TBM Dimensions

External diameter	9.38 m
Length of head	11.58 m
Total length	127.84 m
Total weight	1,470 t

Stations are structurally nearly complete, except for the L1 and L2 stations, where the TBM arrived in advance of excavation. These two must wait for the completion of the tunnel before they can be excavated, and the lining rings demolished. This delay is necessary because of the high traffic density of passing muck trains coming from the TBM.

Geotechnical conditions have remained more or less as expected, with sand and tosco, accompanied by a fair amount of water, thankfully without pressure.

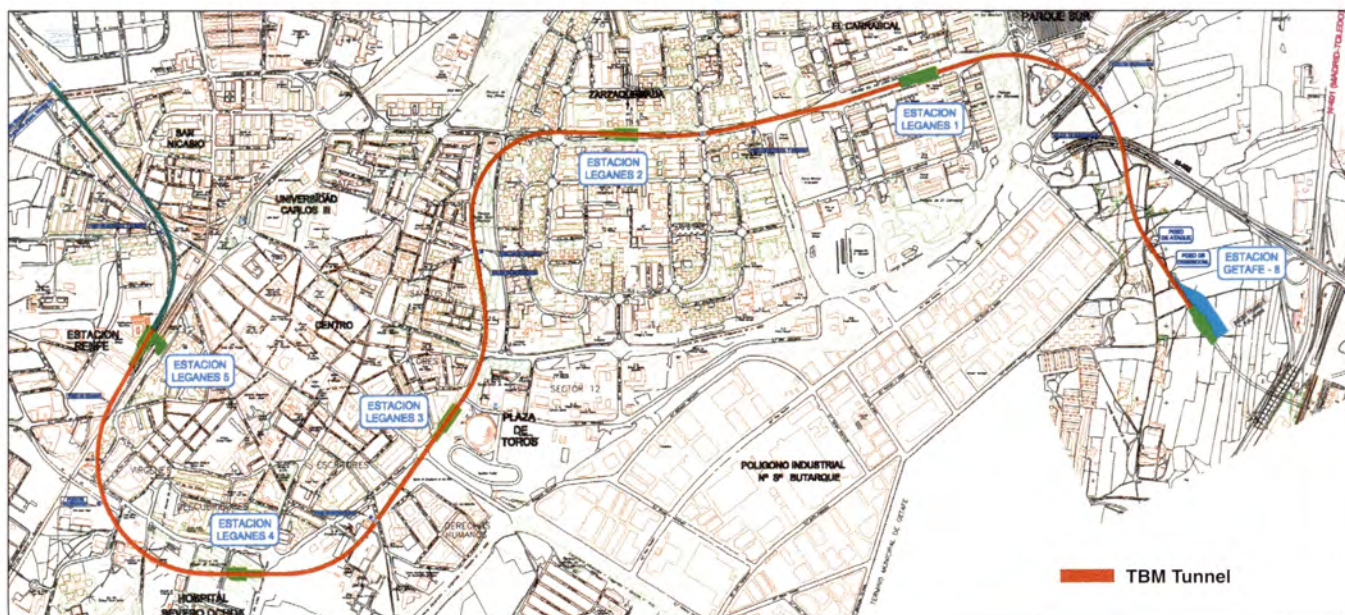
Work commenced in June, 2000, and to date, the following quantities have been completed: walls, 65,000 sq m (97%); concrete, 170,000 cu m (60%); excavation, 800,000 cu m (70%).

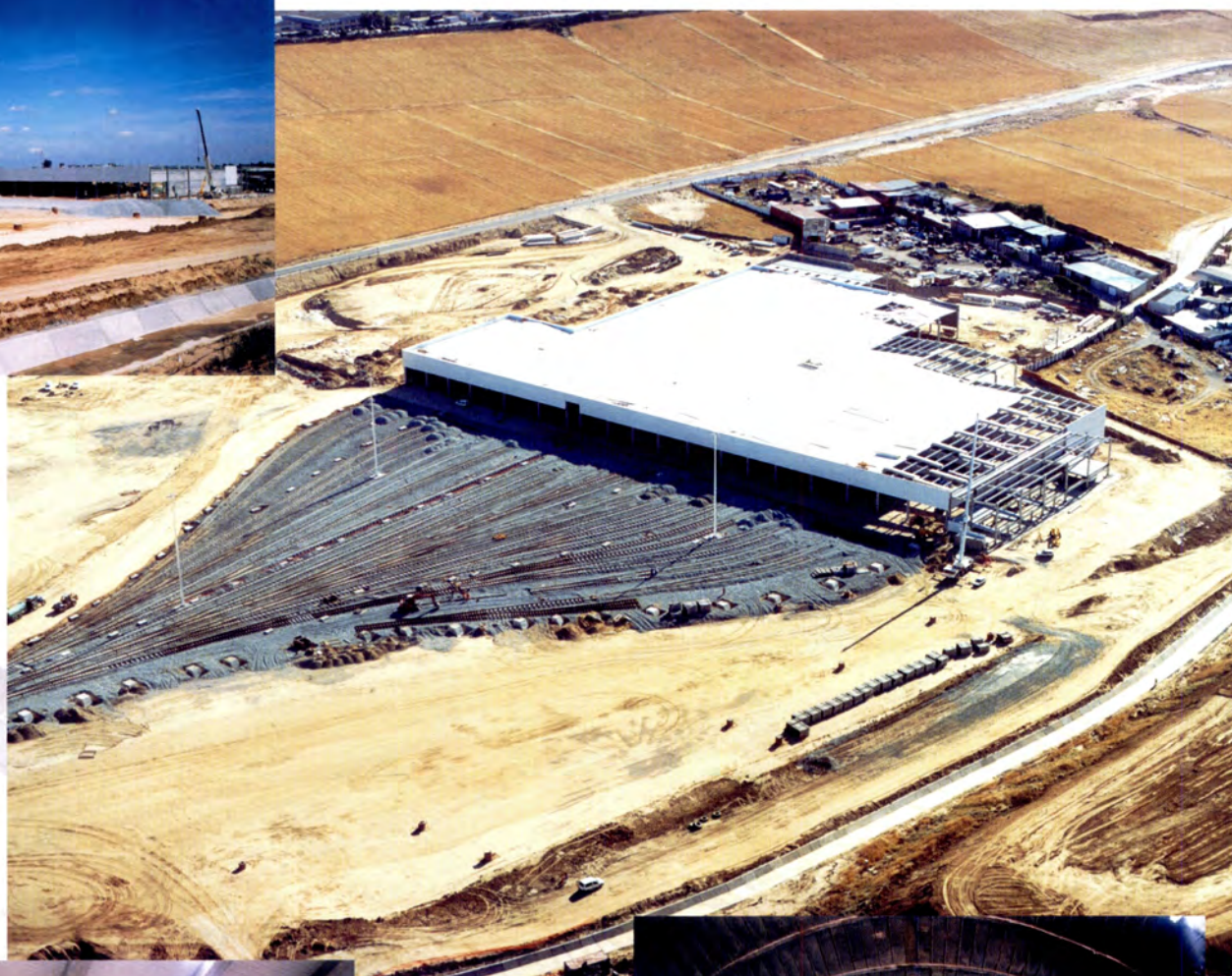


Stretch of finished TBM tunnel.

The tunnel drive commenced on 5th October, 2000 and the following progress has been made: length built, 4,500 m (72%); daily average, 22 m; maximum daily advance, 45 m; monthly average advance, 540 m; maximum monthly advance, 741 m.

Route plan of Contract 6 tunnels with station positions.





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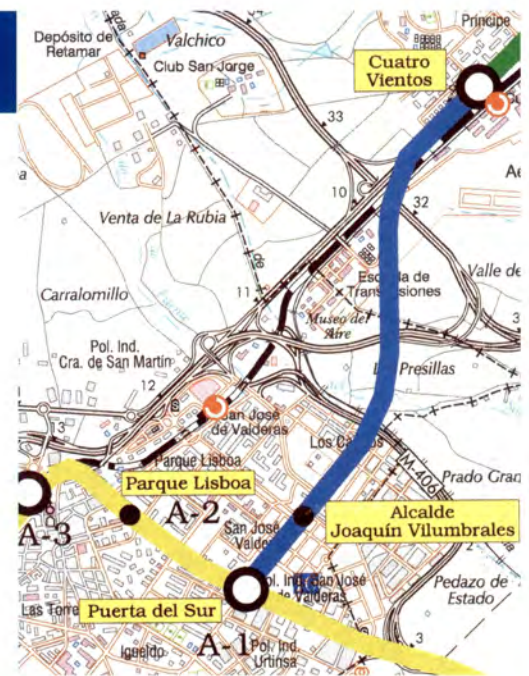


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Line 10 Depot

Cuatro Vientos Depot and Access

Contractor:



The project to build the new depot to serve Metro line 10 was awarded in December, 2000 to Cocheras, the Temporary Union (UTE) formed by the firms Sacyr and Corsán-Corviam. The contract has a period of 12 months and the budget for the award is Pta 6,446,964,415.

The job can be subdivided into the following sections: access tunnel to the railway yard, comprising tunnel between screens and traditional-method tunnel; railway yard and tunnel superstructure; main depot bay; auxiliary building and substation; blowing, washing, go-devil and dock bays; and facilities and sundry features.

Railway Yard Access

The access tunnel to the railway yard requires two types of tunnelling: between screens and traditional. Three junctioning branch lines are being built into the current extension of line 10, just north of the Mimbrenas complex, and this is where the Cocheras tunnels commence. These are single-track branch lines, with lengths of 90 m, 20 m and 15 m respectively, which converge in a telescope into a twin-track tunnel with a length of 677 m. Despite being a small part of the total tunnelling involved for line 10, the depot access tunnels are on the critical path because they are needed for the delivery of the new 6000 class trains. These will start appearing in Autumn, 2001, and will be tested using the proposed line 10 signalling and 1,500 V electrical systems.

The tunnels were constructed by the cut and cover method, using 80 cm-diameter



piles to an average depth of 14 m. The slab that covers the tunnel is of reinforced concrete with an edge of 0.8 m and a width of 8.2 m in single-track tunnels, and width of 5.2 m in the rest, reinforced by 140 kg/cu m steel rebar. Excavated muck from the single-track tunnels was brought out via a purpose-built dirt ramp.

Once the pile screen was cleaned off, a mat was placed on the surface and shotcreted with three layers, reaching a final thickness of 15 cm.

Part of the twin-track tunnel was excavated in four phases beneath the M-40 highway, which is a major ring road around Madrid. The same system of excavation was successfully employed, and lane diversions ensured that the traffic was never stopped.

Cut and cover junctions with line 10 lead to depot at top of picture.



Depot main building will house 30 tracks.

On the side where the railway yard converges, 70 m of tunnel were executed using the Madrid traditional method. The portal of the tunnel was established with a row of micropiles of 127 mm-diameter, with a 5 mm-thick, 80 mm-diameter tubular steel frame, injected with a cement mortar. The face was advanced in 1.25 m increments in the damp, loose ground, with less than 4 m cover to surface.

Railway Yard

In order to execute the railway yard that is located at the tunnel exit, some 300,000 cu m of earth was shifted. This terrain was substituted with selected material, forming a drainage network. After this shaping layer, sub-ballast was spread, and the track was laid on the ballast.

The railway yard is made up of a group of 33 tracks of UIC54 rails with monobloc concrete sleepers. The fastenings are of Vossloh HM type, and there are 40 side-tracks of

TG 0.125 set on akoga sleepers to facilitate a full variety of train movements.

The tracks give access to both the main bay and the blowing, washing, go-devil and dock bays.

Altogether there are approximately 5.4 km of tracks in the yard.

The railway in the tunnels is made up of concreted track set on elastic blocks with Pandrol-type fastenings. This has two complete rerailers in the line tunnel, as well as a sidetrack of TG 0.125, also on elastic block.

Main depot bay

The main depot bay consists of five subdivisions: Parking 1, 2, 3, maintenance, and pits. It has a surface area of 19,152 sq m.

The structure of the bay is of prefabricated concrete in posts, beams and belts. It has a deep foundation made of 50 mm piles. The cover is of ribbed panellised 50 mm plate, pre-lacquered with translucent panels as skylights. The outer closing is also prefabricated concrete, with a white arid finish.

In the maintenance bay there are six tracks, each 120 m-long set on a metallic structure, with "Iberacero" type fastenings and elastic supports.

In the parking bays there are 24 tracks, each 120 m-long and set on rigid blocks.

In the front of the depot, the group of tracks changes onto a monobloc sleeper to allow vehicles to pass.

From the group of tracks, a sidetrack is set up that leads to the building where the bays are located for the blowing and washing of the trains, for parking and maintenance of go-devils, and loading dock.

This project also includes the complete facilities of gas, heating, fire protection, water supply, electrical energy, interior and exterior illumination, grease and oils, compressed air, as well as an anti-intrusion protection system. The entire area is urbanised, with its drainage and sanitation networks.

A drainage channel has been excavated and lined to take surface run-off water from the adjacent M-40 motorway. Access ways will be left, as will footpaths. The perimeter of the entire facility will be fenced to Metro standard, following which the surrounding area will be returned to its previous environmental state.

Auxiliary building and substation

The auxiliary building is adjacent to the main bay and has an area of 2,570 sq m. It has two storeys with pre-stressed honeycomb plates. Here are found the offices, locker rooms, bathrooms and other facilities such as simulation and professional training rooms.

Attached to another part of the main bay building is the electric substation that provides energy to the entire depot. **IB**



Traditional Madrid method connecting railway yard with junction tunnels.

Line 10, Section 2

Twin Tubes from Cuatro Vientos to Alcorcón

Contractor:



The extension of Line 10 Metro of Madrid is split into two sections. Section 1 starts in the station of Puerta de Batán, and ends at Cuatro Vientos. Section 2 runs between Cuatro-Vientos and Alcorcón. The extension will complete the train infrastructure required for the public transport system in the towns around the N-V highway. It will also facilitate the connection of Metrosur with the Centre of Madrid, while improving the utilisation of Renfe Line C-5.

The connection between Alcorcón and Madrid will be much improved, leaving open the possibility of a further extension south. It will also promote future urban construction projects. Interchanges will be effected with the lines to Cuatro Vientos, Príncipe Pío, Nuevos Ministerios and Chamartín, to Metrosur at Ondarreta, and also with interurban bus services at Cuatro Vientos.

The project comprises 6.123 km of tunnel, one station of 121 m, a telescope and a 377 m-long twin-track manoeuvring zone. It also includes 835.6 m of single-track branch lines that connect Line 10 with the train parking facilities for Metrosur and Line 10. The contract value is Pta16,583,275 and the duration is 19 months, from July, 2000 to January, 2002.

Constraints

There are three types of constraints on this contract: those posed by the alignment, foundations of buildings, and existing services.



It has been necessary to co-ordinate the alignment with adjacent facilities, particularly with Section I of the Line 10 extension where the telescope forms the way out of Cuatro Vientos station, changing from twin-track tunnel to twin single-track tunnels. It was also necessary to define the best way to retrieve the tunnelling machine at the completion of its drive.

The alignment has also, of course, been dictated by the need for the connection with Section XII of Metrosur, that traverses Leganés Avenue.

Constructing the telescope at Alcorcón.

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- Execution of Project Design of Metrosur Infrastructure. Section VI: Fuenlabrada Station 5 – Getafe Station 1
- Quality Control of Infrastructure works at Section 2: Extension line 10 to Metrosur
- Control and Supervision of Infrastructure works at Section 1 of Metrosur: Alcorcón 3 – Móstoles 1



<http://www.aepo.es>

The following are the main parameters of design: minimum radius of track curves 300 m, reducing to 80 m along the access route to the train parking facility; maximum ramp slope 3.5%; parabolic parameter, $K_v = 2,000$ m; alignment of stations horizontal, straight, minimum 115 m-long.

Construction

This section of the Line 10 extension project starts at the end of the telescope at the Cuatro Vientos station. The telescope was necessary in order to change over from Section 1 twin-track tunnel to Section 2 twin single-track tunnels.

The first part of the project covers the tunnel between the N-V road and the railway Line C5, near the Cuatro Vientos Station. The twin single-track tunnels start from this point and cross under the railway line, and the south part of the military installations of the Regimiento of Zapador Ferroviarios, going towards the Valley of The Mimbreras, passing under the M-40 and the Golf Course of Club Deportivo Militar Barberán.

Along the Mimbreras section, two big telescopes have been constructed between pile walls that will permit the connection between Line 10 and the branch lines to access the train parking sidings for Metrosur and Line 10. These are situated between the airport of Cuatro Vientos and the M-40. In order to facilitate this connection, three single-track branches have been designed using piled walls. These will allow movement of trains in both directions, towards Alcorcón and Madrid.

From this worksite, the alignment passes under a village of gypsies, as it moves from the municipality of Madrid to Alcorcón. It passes under the M-40 to the N-V, through the park and river of the Canaleja, and the Circumvallation North de Alcorcón Avenue, before entering Alcorcón.

The route into the town of Alcorcón is south along the Alcalde Joaquín Vilumbrales Avenue, and the tunnel continues along similar avenues until its conclusion. It crosses de Castillos Avenue, between the streets of Mercurio and Carballino, to reach the Alcorcón North Station, where the twin tunnels will be completed, and a telescope junction will be built.

Beyond the telescope is the manoeuvring zone, which will have sufficient length to park trains if necessary, without the need to enter Metrosur.

The design of the tunnels provides four emergency exits, all of which are connected to both tunnels. Two of these also act as ventilation points, the third houses a transformer room for the Mimbreras complex, and the fourth a pumping well situated in the lowest point of the tunnel.



TBM launch chamber at Mimbreras.

Also, independently of the four emergency exits, there are three other connections between the twin tunnels in order to ensure they are at intervals of less than 500 m.

The project specifically includes the following works: station infrastructure; ventilation system, wells and ventilation rooms; emergency exits; draining and pumping of water; station architecture; Line 10 extension tunnels to Metrosur; stations and tunnels illumination and station power; replacement of affected services; traffic management; and environmental works.

Zephir locomotives dwarf a conventional Schoema.





Section of completed tunnel shows the Zephir tracks.

First breakthrough of Lovat Cibeles at Mimbreras.



Geology and Geotechnics

The alignment of contract 2 of the Line 10 extension passes through the Madrid facies, on which are occasionally superimposed more recent soils which are sometimes difficult to distinguish because they are of similar origin. These comprise artificial fills and some small parts of recent

alluvial flows, with fine and coarse sand and other materials originating in the decomposition of granites and gneisses from the Guadarrama mountains. Their composition is principally of feldspar sand in a matrix of yellowish clays.

Simply put, the major part of thick materials is present in the upper section, thinning at depth. These major parts do not exclude the participation of one in another. Sand sections have blocks of clay, and in the thin parts there are zones mainly made of sand.

At the start of the alignment, there is mainly fine sand. This was detected continuously in the drilling tests, with high water levels in the area of Cuatro Vientos. This general continuity carries through towards Arroyo de la Canaleja, with occasional lenses that have more coarse sand.

Construction

The station is being constructed with concrete walls and large pile columns that will support the concrete cover slab. Once the cover slab was cast, the traffic could be rerouted over it while work continued beneath. Excavation of the ground between the walls beneath the concrete cover slab was undertaken, and the wall ties at the intermediate levels were installed.

The sequence of work was as follows: excavation of the surface area of the station; installation of the concrete walls; casting of concrete cover slab; excavation under the concrete cover slab, construction of the invert.

The station is designed with the approximate measurements of 121 m length and 26 m width, with central platform of 115 m-long and 16 m-wide.

For the tunnel drive a Lovat EPB is being used, with a closed front and ground pressure balance. This permits a minimal decompression of the ground, and avoids the formation of chimneys. By means of a concurrent injection system that fills up the annular space between the ground and the machine, any slump behind the machine is avoided.

A precast segmental concrete lining is built within the tailskin of the machine, formed by rings of seven pieces and a key. The interior diameter of the ring is 6.7 m, the thickness is 25 cm, and it has a length of 1.208 m.

The type of ring is left-right, and the invert segment is designed to mount the rails of the TBM backup. To drive in a straight line, alternate left and right rings are erected. The cement grout injection is carried out simultaneously with the excavation, but there is also the possibility of post-grouting through the threaded hole used to engage the erector.

Lovat M-288SE Serial 13000 – Cibeles

Earth pressure balance allows tunnel advance with minimum decompression of the ground and avoidance of collapse. The excavation diameter is 7.38 m and the precast segmental concrete lining produces an internal free section of 6.7 m-diameter.

The segments are bolted together within the TBM tail shield, using high-strength bolts.

The TBM advances using 24 hydraulic cylinders that push on the last-erected ring.

The contact surface between the ring and each cylinder is a plate measuring 700 mm-long by 150 mm-wide in order to spread the load as evenly as possible. If any angularity occurs between the thrust plates and the lining, it is necessary to use wedges.

The maximum force of each thrust cylinder is 125 t, which represents a maximum thrust on each completed ring of 3,000 t.

Boring Diameter: 7.35 m

Total length: 8.30 m

Total power: 6 electric motors x 300 hp, total 1,800 hp

Transmission: 16 hydraulic motors (max 4.8 rpm).

Thrust cylinders: 24 x 125 t

Total thrust: 3,000 t

The well was excavated downwards within concrete walls installed from surface, and the connection between tunnels and well is being excavated by the traditional Madrid method of tunnelling.

Provisional works are necessary works at some places: like the Mimbreras complex for the execution of the tunnel; pits for extraction of machinery; and ramps required for station excavation.



Two TBM retrieval pits have been constructed using pile walls: one at Cuatro Vientos, and the other at Alcorcón station. The telescope of Mimbreras was used for launching the TBM in both directions, and will be used for its final extraction.

Muck trains comprising seven 10 m³ Muhlhauser skips, two segment cars and a grout transfer car are too heavy for conventional locomotives on the 3.3% maximum gradients, so rubber tyred Zephir locomotives are used. These have tracking bogies front and rear, and derive their traction from four rubber-tyred wheels travelling on the invert, which has high-friction paths for the purpose. One ring of advance requires 6.5 cars, and takes between 30 and 45 minutes to complete. The Lovat has achieved a best day of 53 m, and 938 m in one month.

The new Dragados segment plant at Talavera is supplying 21 rings/day to Line 10 contracts.

Supply trains in the sidings at Mimbreras.

Line 10 extension of Madrid Metro, Contract 2 Cuatro Vientos – Alcorcón

m ³ of wall excavation/piles	42,558
m ³ of ground excavation	518,979
Kg of steel	9,307,044
m ³ of concrete	156,210
m of tunnel	6,123
m of rail	16,039
Cost	Pta13,881,616,385
Contract duration	19 months (July, 2000 – Jan, 2002)



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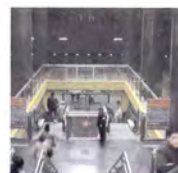
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Line 10, Section 1A

Contractor: 

From Colonia Jardín to Cuatro Vientos



The extension of Line 10 is underway, with two sections currently being built. The first, which is discussed here, was awarded to FCC. It is worth Pta11,348,959,338 and has a duration of 20 months. It will include the future stations of Colonia Jardín and Cuatro Vientos, supporting the north-centre-west Madrid axis, and helping, in the short term, to complement public transport services in the La Latina district. It will serve as the basis for future development of the Campamento town planning operation that involves building two new stations, Darío Gazapo and Parque Europa.

TBM to Cuatro Vientos

The contract was awarded in May, 2000, and commences with a 50 m-long tunnel excavated by the traditional Madrid Method as far as the future station of Colonia Jardín. This area then acted as a launch pit for the TBM La Adelantada, which has since bored 2,791 m of twin-track tunnel in an east-west direction (Madrid-Alcorcón) with an internal circular section measuring 8.43 m in diameter. The TBM was dismantled in a pit located at the Cuatro Vientos station, where the twin-track tunnel connects with an 89 m-long double telescope, executed between continuous screens and pile walls. This section crosses the M-502 and N-V highways, and involved diverting three important water-distribution arteries as well as two major telephone ducts.

The emergency exits from the tunnel, and the ventilation shafts, are being utilised during the operational phase before the start-up. They will be required in the future

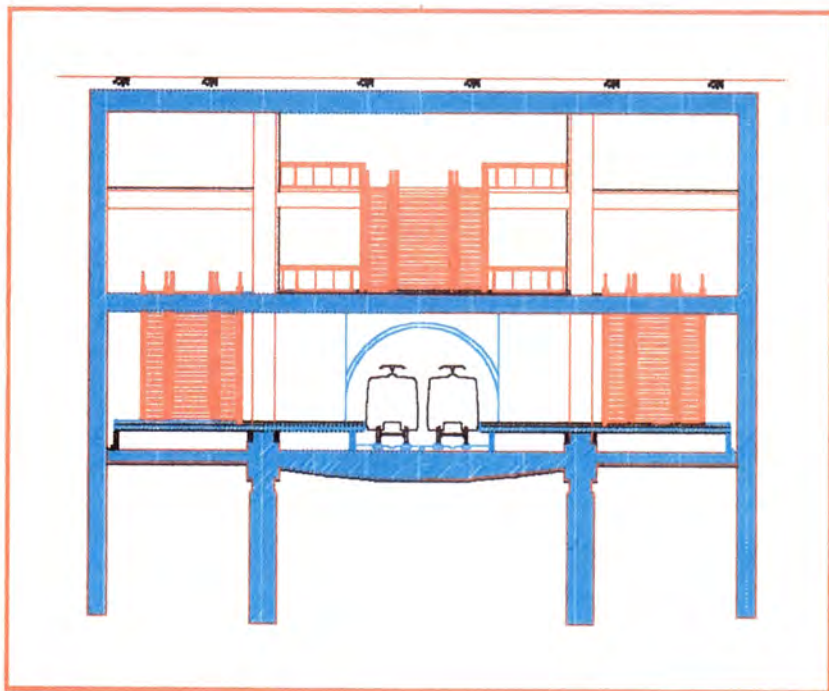


for passenger safety, when the distances between the four stations will be 593 m, 1,027 m and 873 m. This entails a large air extraction shaft, and compatible dimensions on emergency exits 1 and 5 for future ventilation requirements.

Stations

The stations will be cut and cover, using reinforced concrete continuous screens. The Colonia Jardín station will be located under the M-502 Carabanchel-Aravaca highway, which had to be re-routed during its construction in phases. An unusual feature of this station is that, even though it has three levels due to the depth of the tunnel, it will have direct access from Calle Sedano to the vestibule. This will allow it to

Aerial photo of Colonia Jardín station and segment yard.



Section of Colonia Jardín station.

become a future interchange with the inter-urban bus line, and the Pozuelo-Boadilla-Carabanchel light railway.

The Cuatro Vientos station has two levels, and will act as an interchange with Renfe Cercanías Line C-5. This will involve building a 50 m-long tunnel using the traditional Madrid Method under the N-V to execute the north access, and a caisson sunk under the C-5 for the interchange.

Construction

The excavation of the tunnel between Colonia Jardín and Cuatro Vientos is being carried out using a 9.38 m-diameter NFM EPB TBM known as Adelantada. One of the main features of this type of shield is the capability of keeping pressure at the front of the machine, using the spoil treated with biodegradable foams.

Counter-pressure at the front is obtained by using the stored material in a chamber located immediately behind the cutter wheel. This chamber is kept permanently full of material with a plastic-fluid consis-



Installing a station roof support pillar.

tency. This is extracted from the chamber at the same rate that the spoil enters, using a screw ring to unload spoil onto a conveyor, to be transported to muck skips hauled by diesel or battery electric locomotives.

Care must be taken to manage the counter-pressure used at the front of the excavation, to keep it within precise limits. Insufficient earth pressure in the mixing chamber will produce decompression at the front, and result in settlement. Conversely, too much pressure could lead to uplift. Earth pressure should be controlled inside the chamber, to balance the speed of the TBM as it moves forward with the speed of the screw extraction.

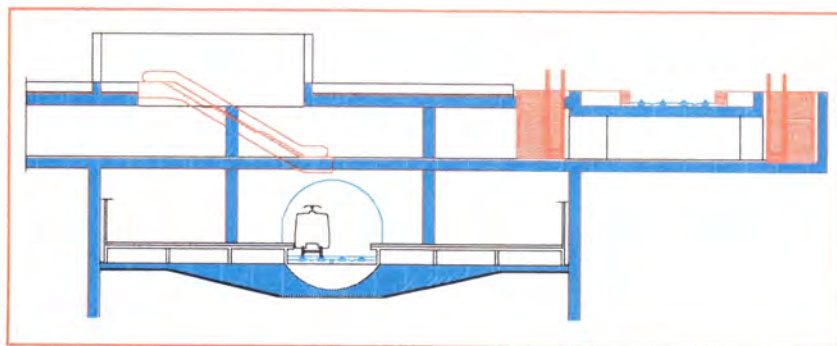
The shield moves forward using a series of powerful hydraulic jacks that thrust against the last ring of the segmental lining. The jacks are fastened to the front section of the shield liner, and their free ends have a footing that pushes on the lining.

Segmental Ring

The TBM has an erection system that can position the lining, which is built of seven reinforced precast concrete segments, with a thickness of 0.32 m and an average length of 1.5 m. The mucking train carries the segments to the front of the TBM in each cycle. The internal diameter of the lining is 8.43 m, in accordance with the gauges the Madrid Metro requires, and the external diameter is 9.07 m.

The universal ring of trapezoidal arches is used. Each ring is made up of seven different segments, the key segment being tapered, and the other six at an angle of

Section of Cuatro Vientos station.





Erecting La Adelantada at Colonia Jardín station.

332.308° to the centre. The width of the rings varies from 1.459 m to 1.542 m.

The rings are joined together using 13 steel bolts set at equal distances apart, with 27.692° between each. There are two bolts per segment, except for the key, which only has one. The ring, therefore, has thirteen different positions of the key segment. Radially, each segment is linked to the next one by four galvanised straight bolts. The basic function of the radial and longitudinal bolts is to ensure the ring remains stable during assembly, and before it is loaded when the shield moves forward. A flexible elastomer seal has been fitted to all radial and longitudinal joints, to make the tunnel waterproof.

The longitudinal bolting and, to a lesser extent, the radial bolting, generate an initial state of compression in the joints, which improves the tunnel's waterproofing.

The segment strengths were calculated taking account of their positioning, storage, transport and manipulation, as well as the force from the jacks during the excavation of the tunnel.

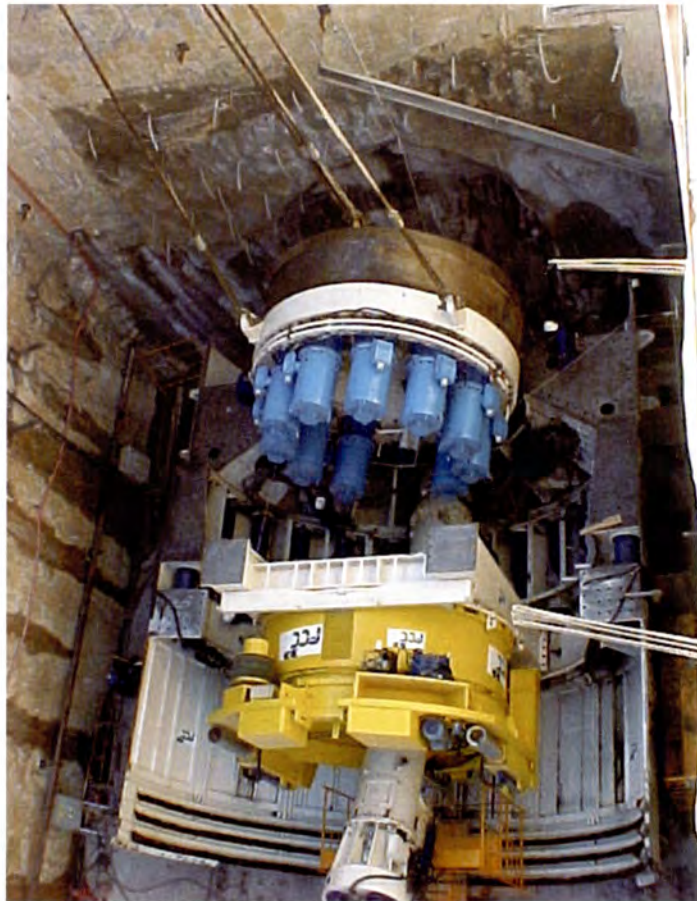
The annulus between the excavated section and the external lining contour is injected quickly, to reduce the risk of subsidence as much as possible. Injection is performed from the tailskin of the shield, and is undertaken during the excavation phase of each work cycle as the shield moves forward. Injection allows the earth to recompress, partially compensating for the relaxation that occurred during excavation. The gap between the excavation contour and the extrados is between 7 and 10 cm thick.

Colonia Jardín Launch

The TBM was launched at the Colonia Jardín station, where a thrust structure helped in the excavation of the first metres of the tunnel, and the installation of the first segmental rings against which the TBM's hydraulic jacks propel it forward.

The Colonia Jardín station will also be used to extract spoil through an access ramp installed for that purpose, and to load segments directly onto the service train. All the installations needed for the TBM to work are available in the area adjoining the station, including crane, gantry crane, transformers, water-regulator deposit and the repair workshop.

Adelantada ready for launch using the reaction frame.





Formwork for concrete
mezzanine floor at Colonia
Jardín.

Breakthrough for Adelantada at
Cuatro Vientos.

m³ of excavation of screens/piles

m³ of earth excavation

kg of iron

m³ of concrete

LM of tunnel (twin track)

LM of rails

Budget

Execution time

The TBM will be removed from the walled area established for that purpose, next to the Cuatro Vientos station.

La Adelantada TBM has exceeded planned progress in this section, reaching an average of 20 m/day, and a best day of 42 m. It also established a world record monthly advance for EPB TBMs of this diameter, completing 939 m in 30 consecutive days.

Typical Geology

The soils in which this section of the work is taking place are typical of Madrid. At the beginning of the section there is an old riverbed, which features tosco sands with thin layers of very clean micaceous sands that contain suspended water pockets and grainy, alluvial soils. There is an aquifer in the crown of the tunnel, made up of alternating levels of sandy tosco and clay tosco that release water when they are cut by the section of the tunnel.

The situation in the rest of the section is similar, but the thickness of the

33,538

366,500

5,708,408

104,600

2,782

12,126

11,384,359,338 ptas

20 months (June 2000-January 2002)



waterproofing layer decreases as the tunnel heads towards Alcorcón. The water table continually crosses the TBM at different heights of the machine's cutter section.

There is no appreciable change in soil type, and sandy soil, tosco sands, and sandy tosco and tosco continue to prevail. At the end of the section, where it reaches Cuatro Vientos station, the tunnel cuts the wall of the super-adjacent quaternary deposits, at which point the water table is below the section, but maintained by a 2 m-thick waterproofing layer.

The project includes a budget of around Pta120 million for subsidence monitoring and instrumentation, both in the tunnel and in particular station walls. Three rings have been used for the TBM tunnel, and extensometers and pressure cells have been placed there, along with regular convergence control.

Four wall modules have been positioned in the stations with different extensometers, inclinometers and pressure cells, and their data is checked during the various execution phases of the work. **T B**

Line 10 Enlargement

Contractors:



Adapting the Gauge of Line 10

By widening the gauge of Line 10, type 6000 rolling stock can be introduced to replace the existing 2000 series trains, thereby increasing the capacity of the line. This project has been in development by the Community of Madrid over a number of years. The construction of the Príncipe Pío Interchange in the late 1990s enabled commuters to transfer from Line 6 to Line 10, maximising the use of both lines. The work to connect and extend lines 8 and 10 also resulted in an increase in capacity demand for Line 10. The latest decision to extend Line 10 to Metrosur to give access to the capital for commuters from the municipalities of Alcorcón, Móstoles, Fuenlabrada, Getafe and Leganés, made the need for an increase in capacity critical.

The Metro trains operating on Line 10 are known as type 2000. These trains are made up of six 2.3 m-wide coaches, with a total train length of 88.32 m. For this type of train, 90 m-long platforms were required.

The gauge-widening project includes the following work: widening tunnels, widening stations, modification of the superstructure, and so on, to enable the type 6000 rolling stock to pass. The new trains comprise six 2.8 m-wide coaches, with a total length of 108.06 m. The platforms will need to be extended to 111.60 m in length. These modifications will facilitate a 63% increase in line capacity, and other improvements will allow the trains to run more frequently.

The objective of this project also entails modifying Line 10 to connect it to Metrosur. To do this, as part of the project, a new station, Puerta de Batán, is under construction between Campamento and Batán stations. This new station will become an interchange for Lines 5 and 10, thereby substituting the existing one in Aluche.



Geotechnical Description

The land on which the city of Madrid stands has been well studied, even more so after the intense ground investigation work and the numerous analyses carried out to classify the ground during previous projects to extend the Metro network. In order to identify the ground where the construction work is to take place, an extensive investigation programme has been carried out, including boreholes with intact core samples. From this investigation it can be inferred, not surprisingly, that the ground in the study area is made up of alternating layers of mainly granular material (miga sand) to markedly clayey material (tosco).

The following strata have been identified:
Miga Sand: contains less than 25% fine material and has low plasticity. The Casagrande classification system situates this material within the silty sands (SM) and clayey sands (SC) groups. It has an angle of shearing resistance of about 35°

Working by night at Puerta Batán station.



Train arriving at Tribunal station.

Plan of the Line 10 gauge adaptation project.

and a cohesion intercept varying between 0.5 and 1 t/m².

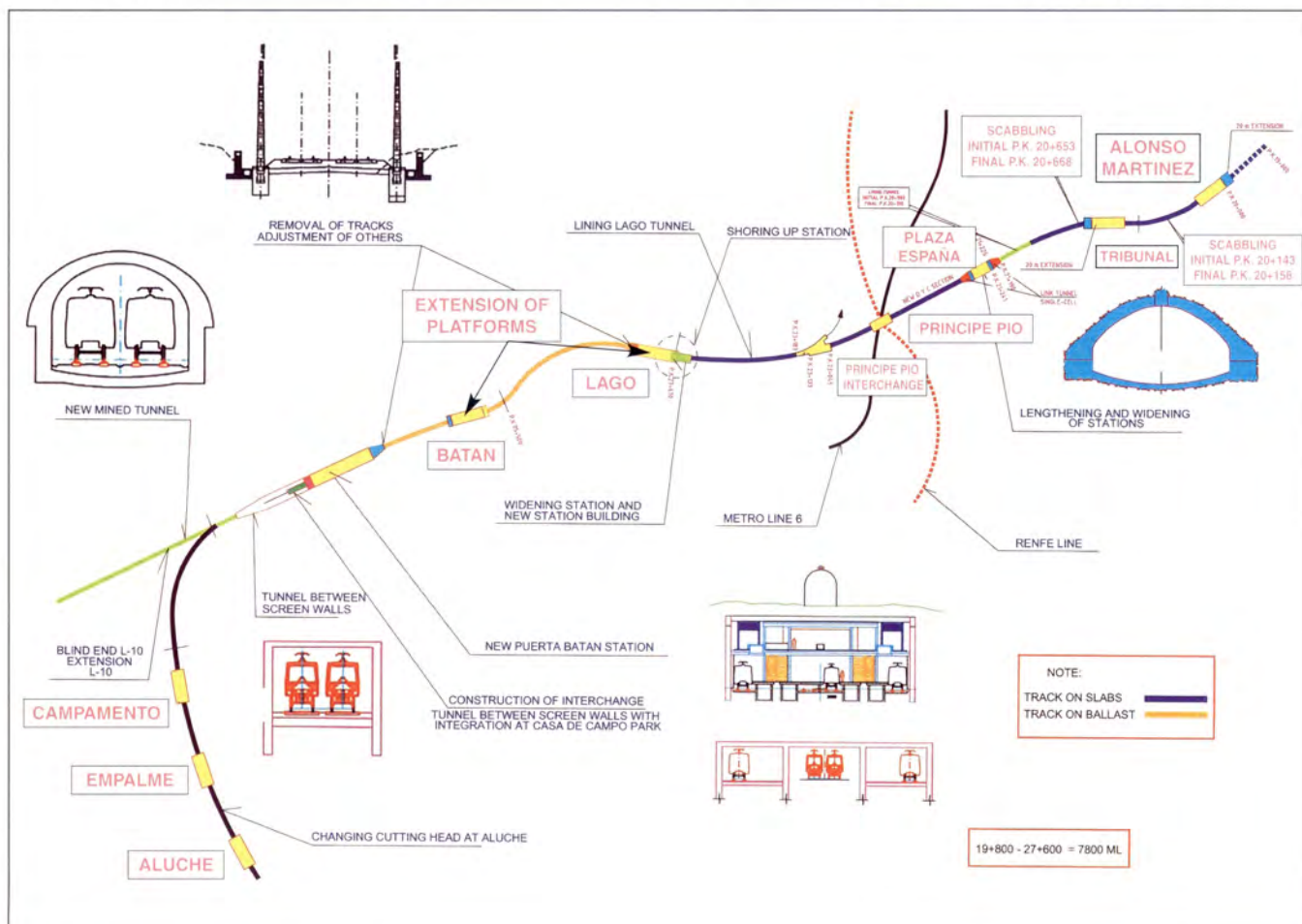
Tosquiza Sand: contains between 25% and 40% fine material and has an intermediate plasticity. The Casagrande classification system situates this material within the clayey sands (SC) group. It has an angle of shearing resistance of about 33° and a cohesion intercept varying between 1 and 1.5 t/m².

Tosco Sand: contains between 40% and 60% fine material and has a low-intermediate plasticity. The Casagrande classification system situates this material in the category of low-plasticity inorganic clays, soils containing proportions of clays, gravels, sands, and silts (CL). It has an angle of shearing resistance of about 32.5° and a cohesion intercept varying between 2 and 2.5 t/m².

Tosco: contains more than 60% fine material and has a high-intermediate plasticity. The Casagrande classification system situates this material within the category of low to intermediate plasticity inorganic clays (CL), and high-plasticity inorganic clays (CH). It has an angle of shearing resistance of about 30° and a cohesion intercept varying between 3 and 4 t/m².

Principal Work

Firstly, it should be pointed out that a great deal of the following work has been made possible thanks to the temporary suspension of trains on the line between Alonso Martínez and Campamento stations, from 1st June, 2000 to 18th April, 2001. Along this stretch, the line was completely renewed. To limit the trauma caused by closure of such a heavily used line, the construction process was optimised to reduce the time necessary to complete the work.



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Underpinning a stretch of tunnel.

As a result, partially re-opening of the line was achieved by bringing the Alonso Martínez and Tribunal stations into service on 20th December, 2000. It is worth noting that, during the time the line was out of service, a special local bus service was established. This operated during the hours of the Metro as an attempt to ease the inconvenience caused to passengers.

A blind-end tunnel, about 760-m long, which will be needed until the inauguration of the extension to Line 10 towards Metrosur, was mined using the traditional tunnelling method, with multiphase excavation.

Removal of tracks between El Lago and Puerta de Batán stations was necessary as a consequence of the increased width of the rolling stock that will have to run along this line. It needs to be widened by 0.5 m between the aforementioned stations. Both tracks are removed to minimise the work on the station platforms. Masonry work is extended, the hard-standing area is worked

Installing track assembly.



on, and retaining walls and new drains are constructed.

Widening the gauge also demands an increase in the tunnel section in various places. This sometimes requires removal of the tunnel lining and replacing it with one of reduced thickness, and elsewhere, simply scabbling to remove high spots.

Lengthening to 111.6 m and widening the Plaza de España, Alonso Martínez and Tribunal underground stations using the German method is being undertaken for the new type 6000 trains. Lengthening and widening of Batán and El Lago stations involves demolishing the central platforms, and lengthening and widening the side platforms. Lifts are being installed for people with restricted mobility, and the toilets and accesses are being redesigned.

Puerta de Batán comprises a new station constructed on Metro land at Casa de Campo Park, which will serve as an interchange between Lines 5 and 10, and will connect with Line 10 extension to Metrosur. This station is being constructed in the open air, using piles and prefabricated or *in-situ* concrete segments.

Line Tunnel

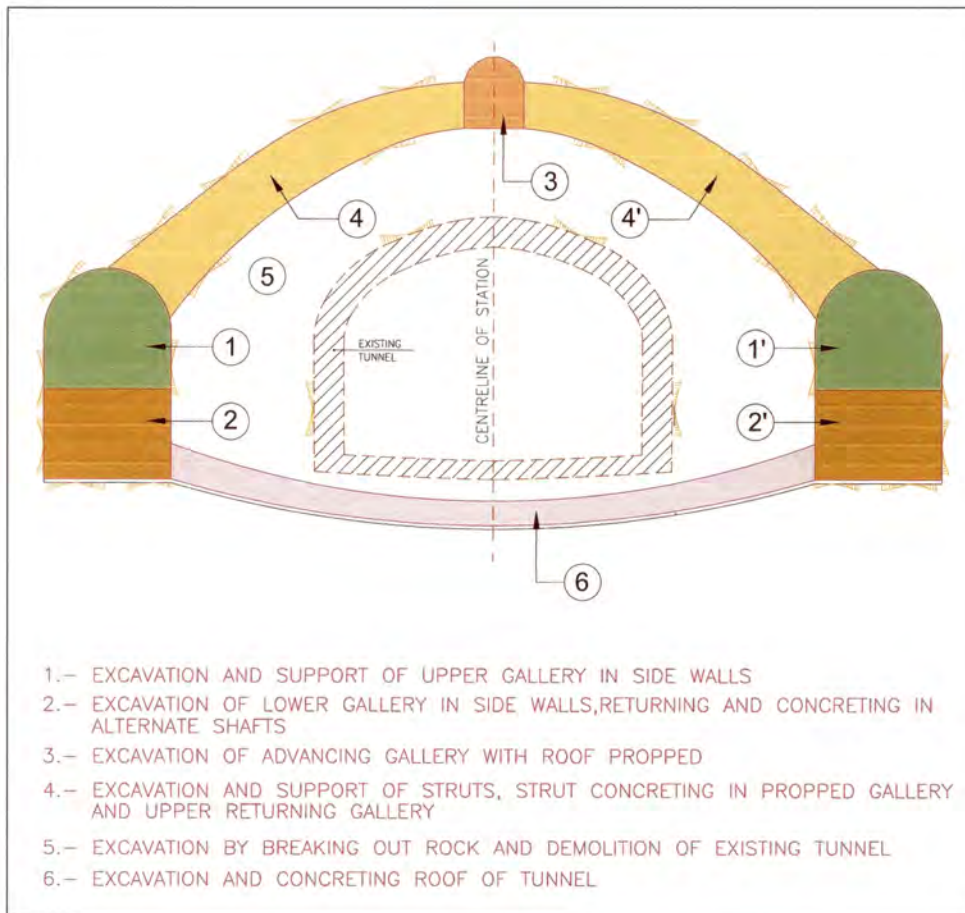
It is important to note that the section is greatly restricted by the geometry of the tunnel and the existing stations, and the aim of the work, to enable type 6000 rolling stock to pass through, should be carried out with the minimum work possible in the tunnel.

About 120 m of tunnel needs to be enlarged, between PKS 21+080 and 21+200. In this way, the new route and the new gauge can run together. To do this, the tunnel arch needs to be enlarged by 90 cm at the worst point, and by 40 cm in the area of the Plaza de España Station. The phases necessary are as follows: partial demolition by sections of the existing side walls, and excavation to the new level of the roof (carried out without ever undercutting the tunnel arch, in 2.5 m sections which are abutted underneath; excavation of a side wall never coincides with an opposite one, and continuous sections are not permitted); concreting and shuttering of the new side wall; excavation of the tunnel roof – after undercutting and concreting all of the side walls, the roof is demolished in 10 m sections, and excavated to the new level; concreting the tunnel roof; injection of fill material at the joints of concrete sections of different ages; and scabbling the tunnel wall, depending on the needs of the section.

In the case of the straight, horseshoe-shaped El Lago tunnel, it was possible to prop with a unique type of support to enable the work. In this case, the tunnel arch only needs to be reduced by 70 cm



German method as used at Alonso Martínez and Tribunal stations.



along a 540 m length, between PKS 23+210 and 23+750.

In some areas, to modify the tunnel cross-section for the new gauge, it just needs to be scabbled, along both the side walls and the shoulders, without needing to excavate the roof of the tunnel. This occurs in six different sections, in total about 225 m long.

After completing this work, and in all the sections where work had not previously been done, the present track, generally on ballast, has to be dismantled, and the new line is laid on slabs, with the sleepers establishing the new gauge.

Lengthening Stations

Lengthening of the underground stations involves a 20 m extension of one of the end walls in Tribunal and Alonso Martínez, and 10 m at each end wall in Plaza de España. The work at Alonso Martínez and Tribunal stations is being carried out simultaneously, by excavating a circular cavern in the tunnel section, using the German method, and then by demolishing and reconcreting the roof. The phases of work are as follows: excavation of the upper section of the side-wall gallery, and shoring with trusses and wooden planks; excavation of undercut, immediately followed by concreting of the side-wall gallery; excavation of the advancing gallery

together with shoring by planks and trusses; excavation for 2 m wide struts, from the side-wall gallery, shoring with wooden planks, stanchions, and metal bracing, concreting of struts, connecting gallery and set-back upper gallery; excavation in phases of the invert, protected by the ring already constructed, and demolition of existing tunnel; excavation and concreting of the tunnel arch in phases; injection of fill material into the extrados.

The process followed in both tunnels has been very similar, only with a variation in the dimensions of the struts. They are less than 1.5 m in the Alonso Martínez Station because they were excavated in miga sand, with abundant water. In this station, it was also possible to excavate the connecting gallery from an existing ventilation shaft.

In contrast, even when the Tribunal Station was excavated in firmer ground, given the existence of old buildings at the surface, some with significant symptoms of previous problems, it was considered necessary to carry out compensation injection, after completing an analysis of the building affected and estimating the surface settlement.

Although the construction of the Plaza de España Station is essentially considered to be the same method as previously described, the reality is quite different. Firstly, as already indicated, the station is



Completion of Lago station and tunnel widening.

extended at the two end walls. Secondly, the station access “crabs” and the escalator exit halls were symmetrically constructed. Thirdly, it was a station with side platforms and a central platform, so it had the corresponding connection tunnels. As a result, although moving away from the strut method previously explained, it would be adapted to the different circumstances, making use of the existing construction, and optimising the geometry of the cross-section of the extension.

The connection tunnel was enlarged, making use of the existing tunnels to construct the side walls of the new section of tunnel, and excavating the roof by the Belgian Method.

Compensation Injection

Extension of the Tribunal Station is also included within the project to adapt the

gauge of Line 10 of the Madrid Metro. The corresponding excavation work and concreting of the struts, demolition of the old station, and construction of the new roof to complete the station, was completed under an area of old buildings, located between La Palma and San Vicente Ferrer streets, behind the National Audit Office.

Although the studies characterised the possible damage to affected buildings as “unappreciable” or “very slight”, the state of the buildings, their age, and the type of structure, made it advisable to take special measures to limit possible settlement. To protect these structures, the necessary compensation injection was calculated and carried out, together with the installation of suitable equipment to constantly monitor the possible movements induced by the nearby excavation work.

For the purpose of monitoring both the movements of the buildings and the ground in the possible area affected by compensation injection, 55 monitoring strips in buildings, and 14 bench marks in the ground, were established. Two bench marks were set for height reference, and to check the precision of the instruments. After that, targets were fixed at the top of the façade, and a measuring strip fixed to the base of the building, to measure any change in verticality of the building.

The results were analysed on a daily basis and compared with the previously established limits of movement, and summarised in a weekly report. During the pre-treatment phase, the objective was to produce heaving of between 0 and 3 mm. Afterwards, the limit for more compensation injections was set at a settlement of 2.5 mm, with respect to the end of the pre-treatment injections.

The observations for verticality have shown that the buildings have not suffered any inclination that could have proven harmful to their structural integrity at any time.

Station Restoration

The Lago and Batán stations are beautiful examples of restoration of old stations. Beyond the strictly geometrical considerations, and adaptation of the gauge, the functionality of the surface level halls has been improved within the fabric of the old buildings.

The Lago Station building is founded on the connecting tunnels of the station, such that the trains entering and exiting the station pass below the building.

The columns of the floor below were supported on the side walls of these tunnels, with the space between the supports being the correct distance for type 2000 rolling stock. The results of a topographical study showed that the columns had been

Covered platform area at Batán station.



constructed in groups at the lower section of the side walls, without any space to increase the tunnel width to allow the type 6000 rolling stock to pass through. It was therefore necessary to modify the foundations of the building.

It was decided not to alter the position of the points of support, in order to conserve the existing buildings as well as possible. As a result, a slab was constructed beneath the existing foundations, to support the loading previously taken by the tunnel walls. This slab will be the upper part of a double-cell frame, which will act as a false tunnel at the exit wall of the station.

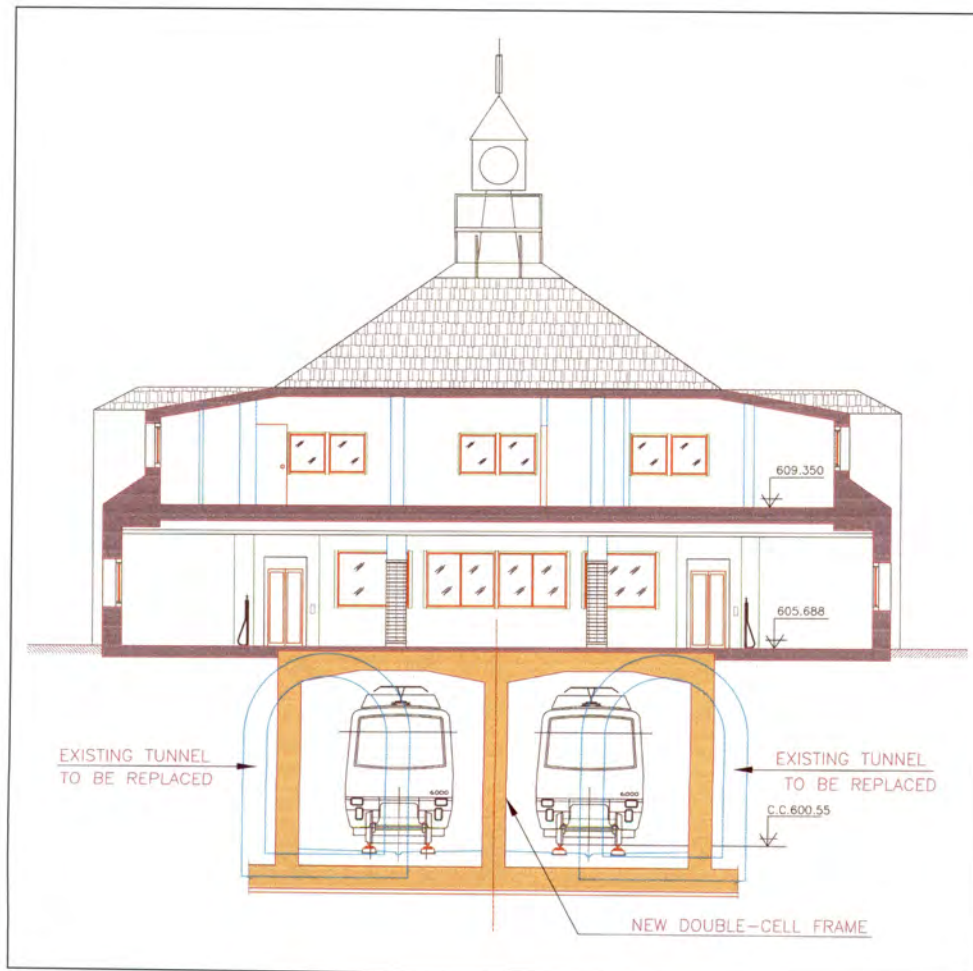
The solution consists of the following phases: construction of an auxiliary metal shoring frame for each of the columns, to transmit the load to the lower level of the future slab; hydraulic jacks used to apply a load on the superstructure which is equal to the load on the shored columns, but in the opposite sense, thus leaving the existing columns completely unloaded; construction of the double-cell frame, including the upper slab; unloading the auxiliary metal frame and returning the loading to the original columns, now supported by a double-cell frame.



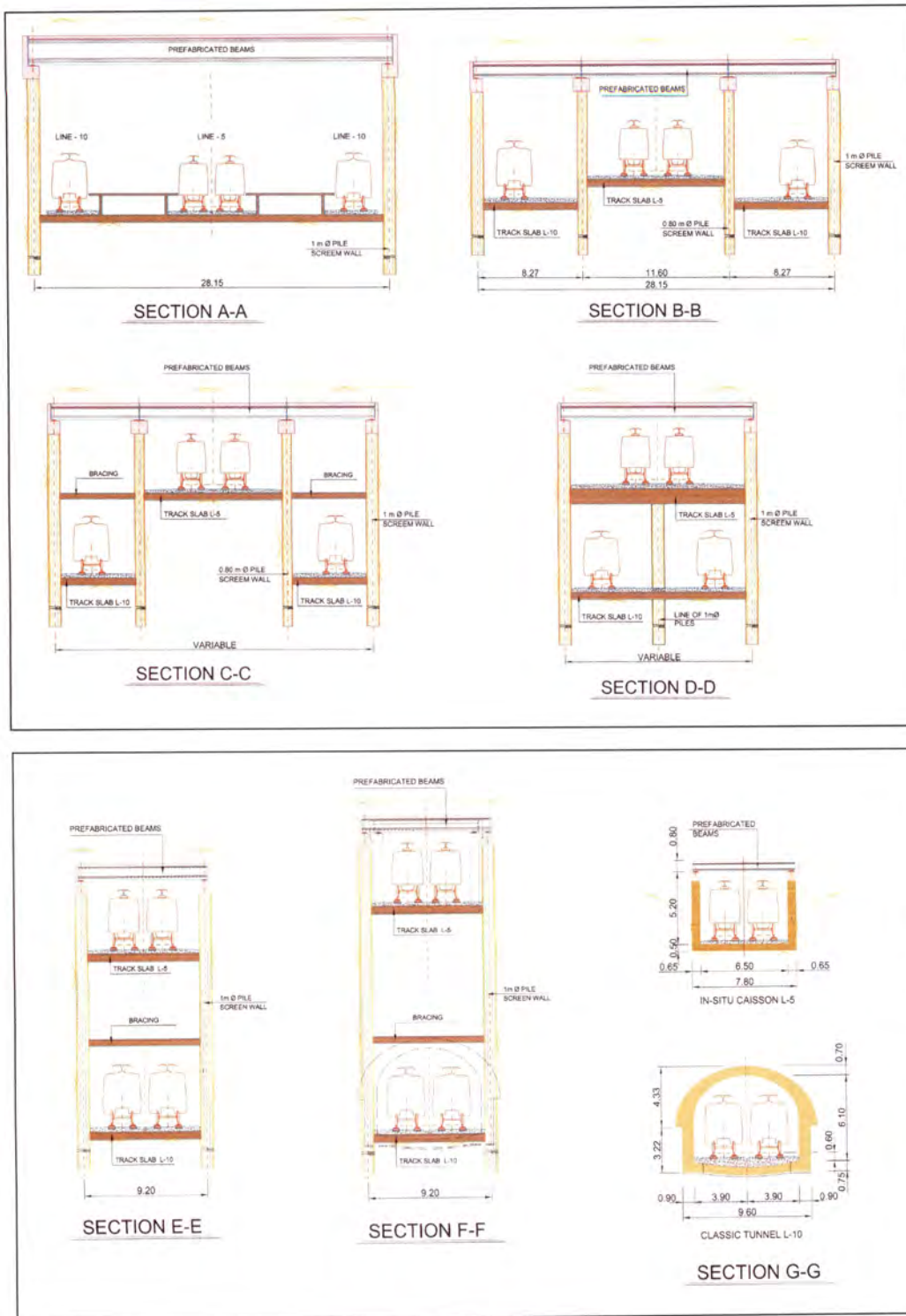
In the Batán Station, the building is at one side of a platform, so the previous process is not necessary. It can simply be redesigned.

By eliminating the central platform, the side platforms can be extended and thereby have sufficient space for panoramic lifts, at both Lago and Batán stations.

Supporting the vestibule at Lago station.



Cross-section of Lago station.



Puerta de Batán cross-section to separate lines 5 and 10.

Puerta Batán Station

The new station, between the existing Batán and Campamento stations, is situated within the section of land presently occupied by Line 10 of the Metro, near where Paseo de la Puerta de Batán road crosses over the line, from which it takes its name. As both lines 10 and 5 of the Metro pass through the station, the transfer of commuters will remain the same. The station has four tracks: the outer lines for

Line 10, and the central lines for Line 5. In the first phase, however, it is planned to use only one of the two available tracks for Line 5.

Amongst the various criteria established for the design of the project, two directly affect the Puerta Batán Station, and both are related to land. The first states that the station should be located within railway land, and the second states that the barrier effect should be minimised as the line passes through Casa de Campo Park.

With respect to these criteria, a long section of the railway line passing through Casa de Campo Park was covered to reduce the barrier effect, thereby giving continuity to this urban park. In this area, which is approximately 800 m long, the new tracks, with an axis precisely coinciding in plan view with the axis of the old route, run below the level of the old track. The station is also completely integrated within the aforementioned covered area.

The length of this covered area is limited by two lines of piles, the upper sections of which are capped by interlinking beams, and an earth retaining screen wall. The characteristics of the retaining wall are as follows: 1 m-diameter piles *in-situ*; 1.2 m between centres of piles; 19 m minimum depth; 32 m maximum depth; lower section gunited with 70-mm thick layer covering metal mesh pinned to the piles.

The pile capping on the interlinking beams supports the roof construction. This consists of a series of pre-stressed bevelled beams, lights and variable separation, and a 250-mm concrete slab cast *in-situ*, with light reinforcement.

The new tunnel, which will be excavated using the traditional Madrid Method, commences at the end of the covered section, at a depth of about 20 m. The extension to Line 10 will run through the tunnel, to the connection with Metrosur. **T B**



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