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.

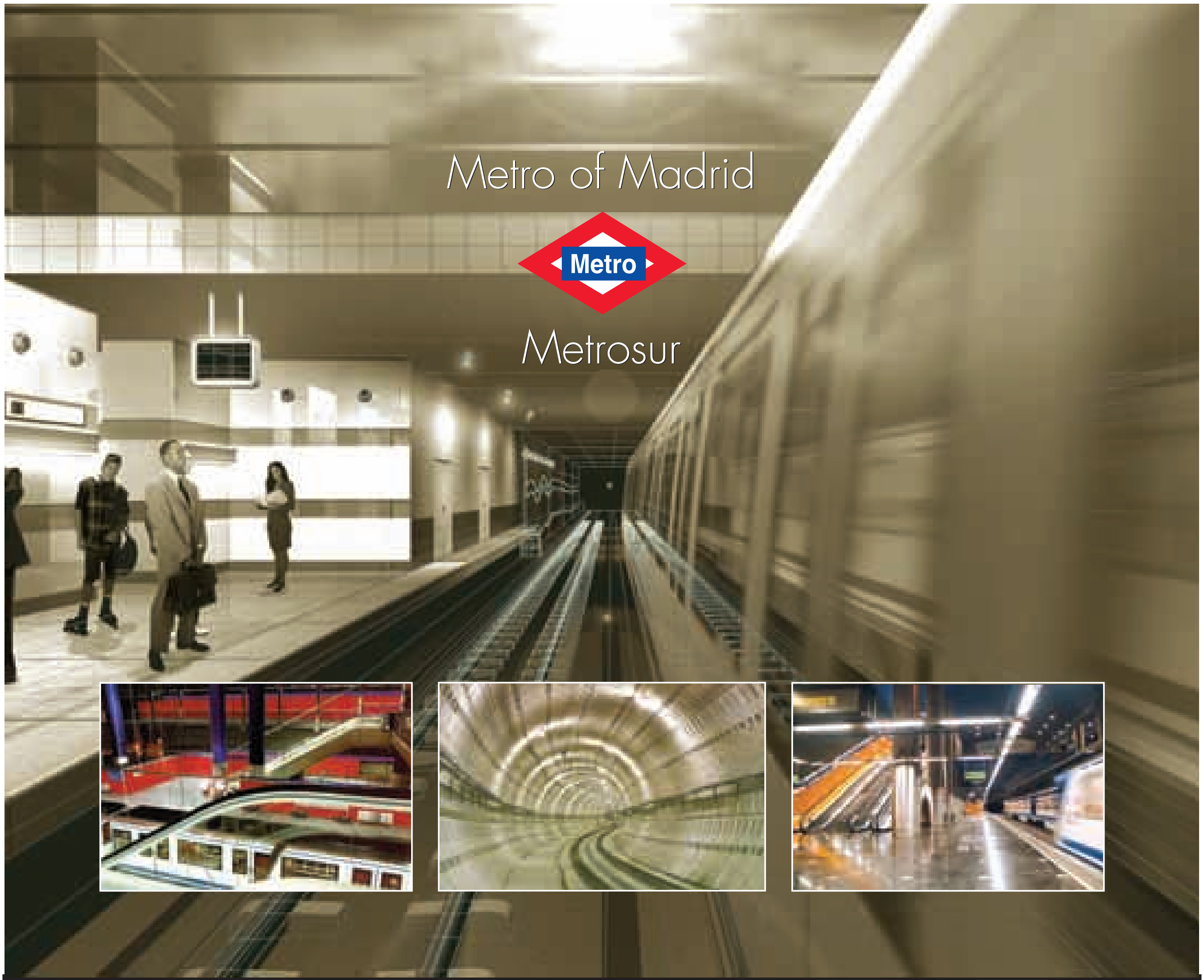
Concreting alternate sections of false tunnel roof.

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 know 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



engineering the future

TYPSA has designed and/or supervised the construction of 84 km and 75 stations of Madrid Metro, actively contributing to its extension since 1995:

- L-4 Section Esperanza - Mar de Cristal
- 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

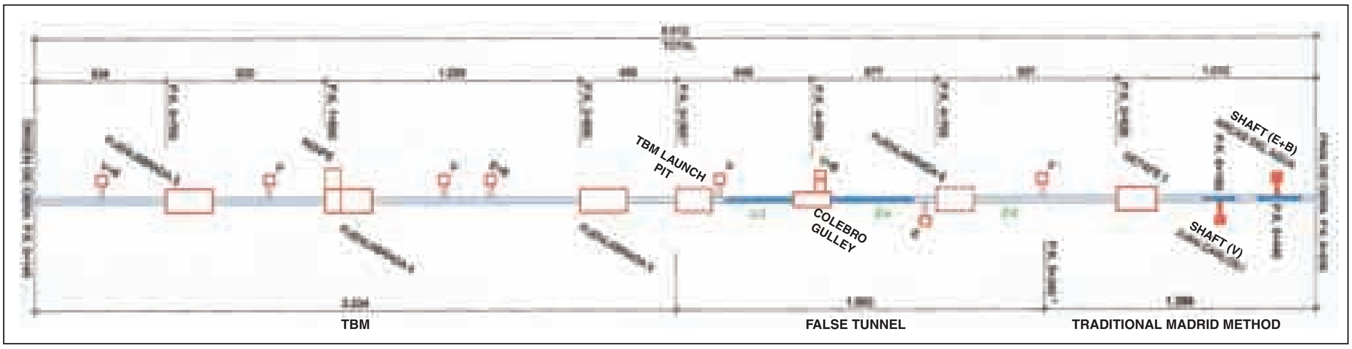
The contract can be divided into three clearly different parts – in kilometre order.

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.

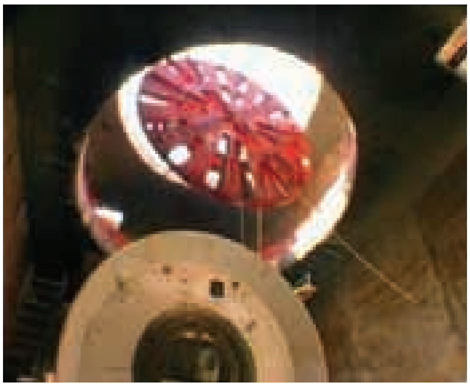
Lastly, from the M50 to the end of the contract, a distance of 1.4 km, the tunnel is being constructed using the traditional Madrid method. This part contains the G1 station and two shafts.

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,

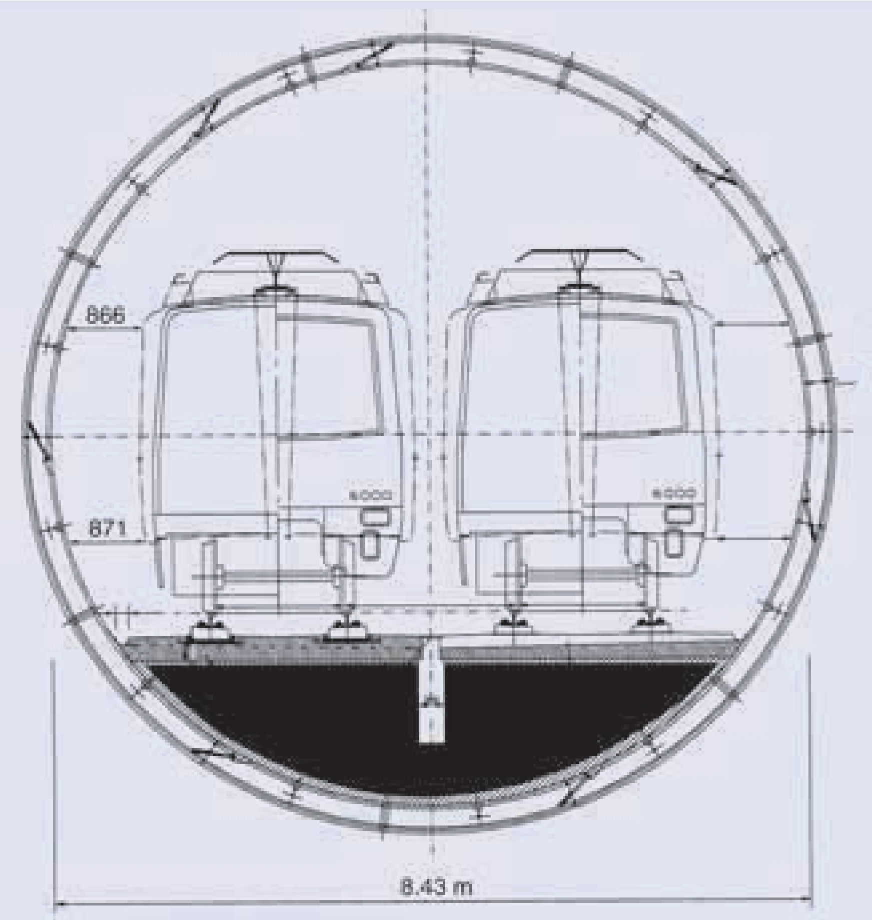
Section of EPB TBM.

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.



Standard TBM section for twin track tunnel.

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.

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 m^3.

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.

Box jacking arrangement to cross beneath Renfe tracks.