

Underpass in O'Donnell Street in Madrid

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Abstract: At the end of 1997 the Town Hall of Madrid, due to the increasing traffic in O'Donnell Street towards Madrid airport, decided the construction of an underpass in O'Donnell Street, below the underpass already existed in Doctor Esquerdo Street and above the underground tunnel of line 6. The new underpass must threading it between the other two and with a limited height clearance, so that the floor of the Doctor Esquerdo's tunnel was the roof of O'Donnell's tunnel.

Due to these circumstances, besides the technical difficulty previously mentioned, the tunnel was in the moment of execution of the work, the deepest (14 m under the surface of the street) and the longest (547 m) of the existing ones up to this date in Madrid.

As additional circumstances of the project and to the execution there were numerous services affected, since the site corresponds to an urban central area: telephony, electricity, supply of water, sewage, etc.

Résumé: À la fin de 1997 l'Hôtel de Ville de Madrid, comme la conséquence du trafic augmentant dans la rue O'Donnell vers l'aéroport de Madrid, a décidé la construction d'un passage souterrain pour la Rue O'Donnell. Au-dessous du passage souterrain a existé dans la rue Docteur Esquerdo et au-dessus du tunnel souterrain de ligne 6, était nécessaire le construire entre les autres deux et avec une hauteur limité, pour que le 'étage du tunnel du Docteur Esquerdo soit le toit du tunnel d'O'Donnell.

En raison de ces circonstances, en plus de la difficulté technique précédemment mentionnée, le tunnel était dans le moment de l'exécution du travail le plus profond (14 m sous la surface de la rue) et le plus long (547 m) des existants jusqu'à cette date à Madrid..

Comme les circonstances complémentaires du projet et à l'exécution il y avait de nombreux services affectés puisque le site correspond à un secteur central urbain : téléphonie, électricité, provision d'eau, égouts, etc.

Keywords: Excavations, foundations, injection, piles, retaining walls, tunnels.

INTRODUCTION

At the end of 1997, the city authorities of Madrid, motivated by the density of existing traffic in O'Donnell's Street, one of the principal arteries of Madrid with its exit to the surrounding motorway of M-30 decided to call for bids for a project and execution of work for the construction of an underpass under O'Donnell Street with its exit towards the M-30 and M-40, with a double carriageway and an alone sense of traffic (Figure 1). The crossing of Doctor Esquerdo Street, constituted a traffic black spot.



Figure 1. Aerial view of O'Donnell's tunnel

The bidding was won by the UTE CORSAN-RODIO with the project made by D. Ángel Novillo and by D. Carlos Jurado, author of this communication, who was the Technical Director of CORSAN's contractor and engineering firm in the date of the bidding. The Director of the work was D. Jorge Presa Matilla. The work had as the most important technical difficulty the existence of one tunnel under Doctor Esquerdo Street and, below this, Line 6 of the underground network. It was a project requirement for the new tunnel on O'Donnell Street to be threaded between the other two and with a height so that the floor of the Doctor Esquerdo's Street tunnel was to be the roof of the O'Donnell's Street tunnel (Figure 2).

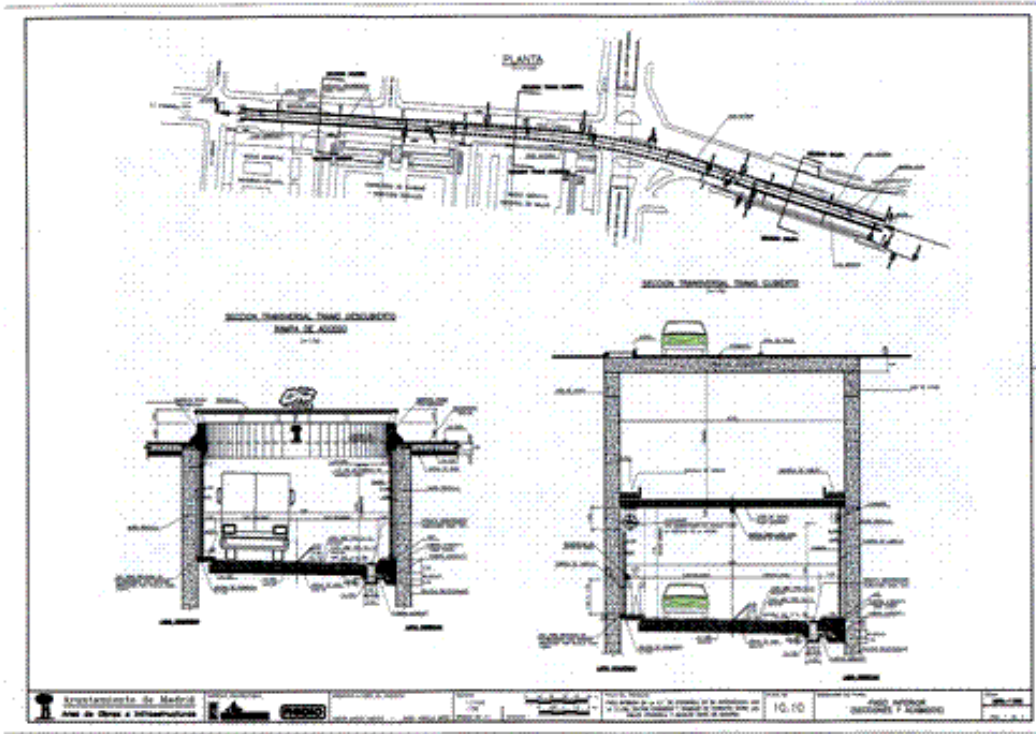


Figure 2. Plant and sections of the underpass

Due to these circumstances, besides the technical difficulty previously mentioned, the tunnel was the deepest at the time of execution of the work (14 m under the road surface) and the longest (547 m) of the existing ones up to that date in Madrid (Figure 3).

Table 1. Characteristics of the work

Name of works	Underpass in O'Donnell street in the intersection with Doctor Esquerdo street and the connection of O'Donnell and Alcalde Sainz de Baranda streets
Situation	MADRID
Property	Area of Works and Infrastructures of the Town Hall of Madrid
Firm contractor	U.T.E. CORSAN-RODIO
Beginning of work	May 1998
End of work	April 1999
Budget	1,026 M Ptas.
Project	Carlos Jurado Cabañes – Ángel Novillo Ortiz
Works Director	Jorge Presa Matilla
Underpass length	546,962 m.
Road length	559,390 m.
Retaining wall area	8,708 m ²
Prefabricated wall area	1,657 m ²
Length of piles ø 650 mm	902 m
Length of piles ø 1800 mm	76 m

The compulsory condition of the design imposed, was that the maximum longitudinal slope of the tunnel was 7% and that the beginning of the same one in exit direction of Madrid, was realized allowing access of traffic proceeding from Maiquez Street, which imposed very restrictive conditions for the turning of vehicles of large tonnage.

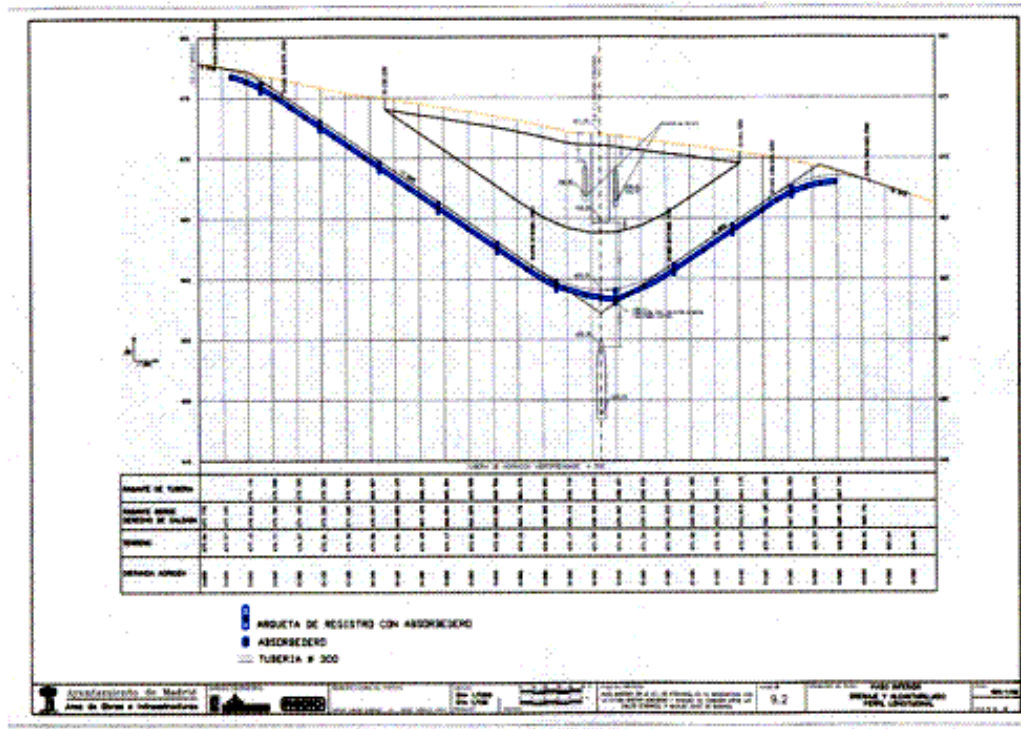


Figure 3. Longitudinal profile of the O'Donnell Street tunnel.

An additional point, important to the project and to the execution of the work, was the numerous existing services affected, since the site corresponds to an urban central area: telephone, electricity, supply of water, waste water, etc. Among them were two service galleries that circulate on each side of Doctor Esquerdo Street and made of reinforced concrete with transversal section in vault, with an exterior width of 3.10 m and a maximum interior height in the middle of the arch of 2.65 m. The walls were 0.40 m thick (Figure 4).

Another affected service was a great sewer collector which passed along O'Donnell Street, constructed by hand and affected by the *in situ* concrete sheet pile walls of the new underpass, and which was necessary to divide into two collectors on both sides of the works, and to rebuilt by the same construction method for a length of approximately 1500 m.

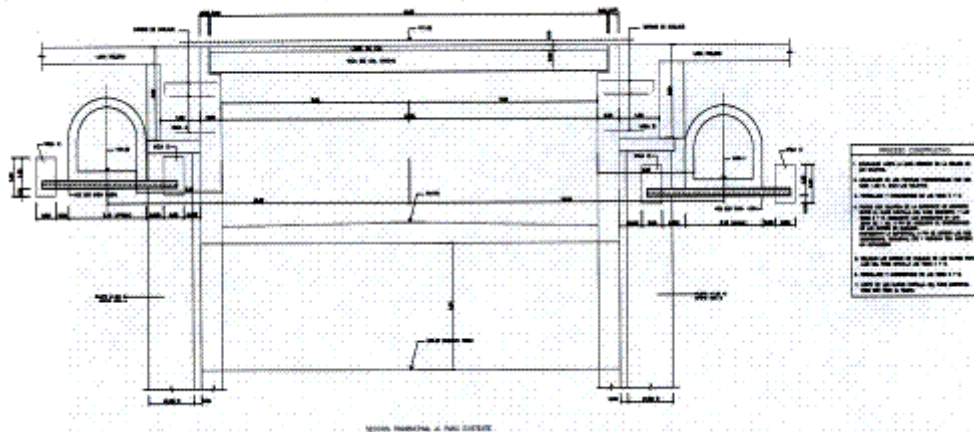


Figure 4. Service galleries close to the existing underpass of Doctor Esquerdo Street.

The work included the remodelling of the intersection with Alcalde Sainz de Baranda Street, as well as the entry from the neighbourhood of the Elipa District, close to O'Donnell Street, which implied the construction of a pre-stressed concrete bridge, of two spans with 44 m. of total length, over the link between O'Donnell and Sainz de Baranda Streets (Figure 5).



Figure 5. Aerial view of the link between O'Donnell and Alcalde Sainz de Baranda Streets.

ALTERNATIVES OF EXECUTION OF THE TUNNEL

The most difficult part of the project and of the work was the intersection of O'Donnell Street with Doctor Esquerdo Street, where it has been indicated above, there was an underground system tunnel below the new underpass and the existing underpass of Doctor Esquerdo Street above. Between them the new O'Donnell Street tunnel would be constructed with a strict height control and almost perpendicular to both.

To solve this technological challenge, three alternatives were proposed in the winning bidd:

- Tunnel constructed under the protection of an umbrella of horizontal micropiles.
- Tunnel constructed by means of pushing a caisson of reinforced concrete.
- Tunnel constructed by means of the creation of *in situ* concrete sheet pile walls under the existing underpass and after the construction of a top slab rested on them, constructed by means of 11 pre-stressed, precast beams PLN-45 and a slab of compression of 0.25 m of thickness, constituting a bridge of 10 m in length and 14.50 m in width.

The work was awarded in April 1998 for the third of the three alternatives at a cost of €6,166,384 and a construction period of 11 months. The works began in May 1998, with completion anticipated in April 1999.

GENERAL DESCRIPTION OF THE WORK

The work included the construction of the underpass at the crossing of O'Donnell Street with Doctor Esquerdo Street, as well as the construction of two links between the O'Donnell Street and Alcalde Sainz de Baranda Street and other complementary works.

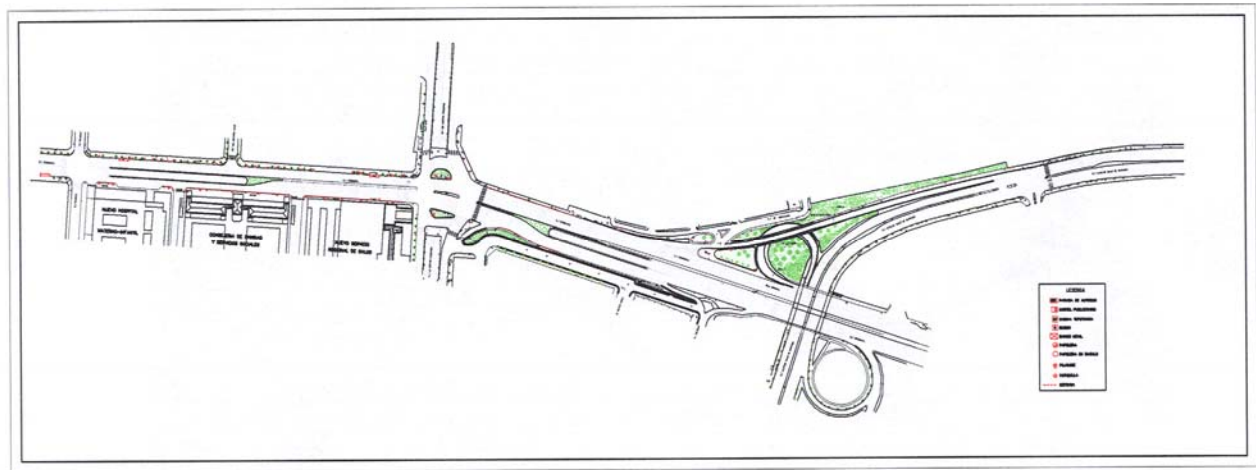


Figure 4. Plan of the works site

The transverse section of the underpass was formed by a road of two lanes (direction M-40 outside the city) of variable width, between 3.25 m and 3.50 m, with two sidewalks of 0.75 m width (Figure 2). In vertical section, the axis of the underpass consists of two straight alignments of 218 m and 121 m respectively, joined by a vertical circular curve of 525 m radius, with corresponding curves of transition (Figure 3). The maximum slopes were 7% at the entrance from Maiquez Street and 6.85% at the exit to the M-30. The total length of the underpass was 547 m (Figure 3).

The work was known popularly as "the retunnel" because of its position between the existing Doctor Esquerdo's underpass (above) and the tunnel of Line 6 of the underground network (below). The work on the O'Donnell's Street tunnel used 8,078 m² of *in situ* concrete sheet pile walls, of 0.50 m and 0.60 m thickness.

There were two slabs of reinforced concrete, the upper under the surface of the street supporting the traffic and of 0.60 m thickness and 9.00 m span, and the lower one of 0.30 m thickness and an equal span. Between the two was an opening of 5.20 m maximum height, useful for the installation of the systems to control gases and fires in the tunnel. The total surface area of concrete slabs constructed was 2,750 m², with an area of 39,252 m² of roads and pavements. In the following table is presented a summary of the quantities of the work.

Table 2. Work quantities

Reinforced Concrete Volume	9,599.3 m ³
Reinforcing Steel	417,510.6 Kg.
Prestress Steel	6,664.9 Kg.
Excavations	52,902.0 m ³
Masonry Concrete	5,593.1 m ³
.Length of Soil Consolidation Injection	473.5 m
Road Bituments	6,816.3 T

At the intersection with the existing underpass of Doctor Esquerdo Street, injections of consolidation which fulfilled the vault of the underground Line 6, executing finally the intersection with the existing underpass, by means of two *in situ* concrete sheet pile walls of 1.00 m thickness and changeable lengths between 6.00 and 7.00 m., being the toe of the sheet piles between 2 and 3 m over the existing vault of the underground Line 6. The available height to 'thread' the new underpass in the crossing zone was approximately 9 m. Additionally, numerous important municipal and non-municipal services had to be dealt with:

- Dividing the existing 725 m of sewer collector on the line of O'Donnell Street into two collectors on both sides of the site work.
- Supporting of two existing service galleries of reinforced concrete, on both sides of Doctor Esquerdo Street and the corresponding concrete sheet walls of the existing underpass.
- Diversion of the terrestrial network of optical fibres, belonging to Retevisión.
- Services for natural gas, telephone, water supply, sewage, electricity, etc.

The structure of the underpass was solved on both sides of the Doctor Esquerdo underpass by means of two *in situ* concrete sheet pile walls of 0.50 m thickness and with two strut bracings, formed by the cover slab to street level of 0.60 m thickness and a thin slab that was serving as the roof to the new step of 0.30 m thickness, joined to the sheet pile walls.

In the zone of the crossing there was another important aspect produced by the interference of the structure of the new underpass with the existing one. Specifically, this structure is formed by two concrete sheet pile walls joined by a reinforced concrete slab on the top. Given the length of fixing of each one, its demolition was necessary for the construction of the crossing with the new underpass.

To ensure the stability of the sheet pile walls of the existing underpass during the phase of cutting them to leave the hollow for the new underpass, a large concrete beam was projected to hang the existing sheet pile walls. The beam was 1.50 m wide and 3.60 m high and it was supported by two piles placed on both sides of the new sheet pile walls, with 1800 mm diameter and 19 m length, so that this did not compromise the vertical stability of the existing panels, affected by the demolition. In addition, in the lower part, the panels mentioned above were anchored to the crossing structure that was constructed from the interior of the existing underpass and which is described later.

The crossing structure consisted of a 'bridge – slab' of 10 m length and 14.50 m width, constituted by 11 pre-stressed concrete beams in the shape of an inverted T (11 PLN-45) of 0.45 m height, arranged together, plus a reinforced concrete layer of compression with a variable height from 0.10 to 0.25 m. The concrete beams were supported on neoprenes 100 x 250 x 19 mm with the concrete slab fixing in the abutments constituted by the tie girder of 0.50 m thickness and with a changeable length between 6.00 and 7.00 m. Furthermore, this crossing structure has a transition slab at every abutment of 0.20 m thickness to avoid a sudden jump of the surface road of the upper tunnel at the crossing with the lower one. This solution permitted continuous traffic flow in the current underpass, constituting in addition, the roof of the new underpass in the crossing zone.

The crossing structure was finished by a slab of reinforced concrete of 0.30 m thickness, anchored to the concrete sheet pile walls and forming a box that, besides making the crossing vehicles possible for the new underpass, allowed the connection to the same one of the concrete sheet pile walls of the existing underpass without transmitting appreciable stresses to the structure of the tunnel of the underground Line 6 and reinforcing the monolithic response of the set formed by the new structures and the existing ones (Figure 6).

To complete the latter aspect, a campaign of consolidation injections was carried out with low pressure in the surrounding areas of the vault of the underground tunnel, to consolidate possible cavity zones that could have been present in the back face of the vault and to form an 'area,' that would guarantee the correct behaviour in the surrounding zones of the new works.

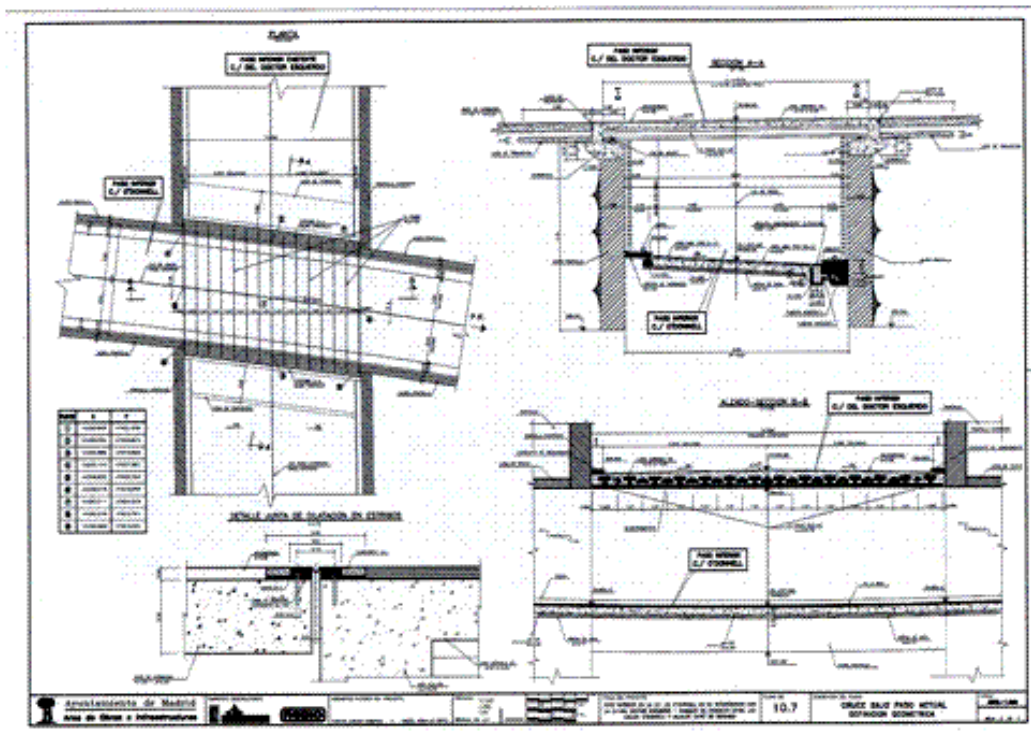


Figure 6. Structure of crossing with Doctor Esquerdo's underpass

Besides the tunnel, the work included the connection of O'Donnell Street with Alcalde Sainz de Baranda Street, which was resolved with a circular link in the sense O'Donnell-Sainz de Baranda and one pre-stressed bridge over it with two spans of 44 m length, 1.00 m height and 7.00 m width including two sidewalks of 1.00 and 1.50 m. The transverse section was of a trapezium shape, lightened with lateral wings where the sidewalks were placing to both sides of the road of 4.50 m height. The abutments of the structure were joined to the ground containing wall (Figures 5 and 7).



Figure 7. Bridge over the link to Alcalde Sainz de Baranda

THE SERVICE GALLERIES

An important point in the execution of the work was the service galleries to both sides of Doctor Esquerdo Street, which constituted an important barrier for the execution of the concrete sheet pile walls and whose important selfweight was necessary to support it in the phase of excavation of the hollow of the tunnel under them. These galleries consisted of reinforced concrete with a roof arch having a free distance between the walls of 2.50 m and an interior maximum height in the middle of the arc of 2.65 m.

During the construction of the concrete sheet pile walls there had to be interruptions in use of on both sides of the service galleries. Alternatively, having excavated the tunnel under the gallery there would have been an unsupported span of 9 m, passing from working in compression to working in flexion, for which they were not designed. This was not acceptable. So, it was necessary to support continually the total length of the galleries in a provisional or permanent way. To resolve this it was necessary to construct two large beams of reinforced concrete (Figure 8) on both sides of the galleries. These beams would have a width of 0.80 m and a height of 1.50 m and would be supported by two piles of large diameter ($\phi = 1800$ mm) on both sides of them. In these beams were embedded metallic profiles HEB280 every metre for reinforcement.

GENERAL DESCRIPTION OF CONSTRUCTION PROCESS

In a schematic way, the construction of the concrete sheet pile walls on both sides of the crossing were begun first, including the corresponding tie beams and the cover slab. Besides, it was realized that the crossing structure from the interior of the existing underpass, diverting the traffic for the other half of the existing underpass, excavating the concrete sheet pile walls in the zone of the crossing by conventional methods, due to the reduce height, was insufficient to introduce machinery for sheet pile wall construction.

Later in the adjacent zone to the concrete sheet pile walls of the current underpass, there were constructed the four large diameter supporting piles and the large hanging beams for the sheet pile walls of the existing underpass. Also, the structures for supporting the service galleries were constructed.

Next, was constructed the area between the concrete sheet pile walls with classic systems up to the level of the roof slab, constructing this up to the zone of crossing.

The excavation of the zone of crossing, sheltered by the new concrete sheet pile walls of the structure, was realized from one of the sides for zones of 2.50 m, constructed each of them up to the floor of the underpass with a reinforced concrete slab. For this operation, during the months of July and August 1998, the traffic was cut in the Doctor Esquerdo's Street existing underpass.

Finally, once the whole excavation was finished, the paving, finishings, facilities, etc. were installed.

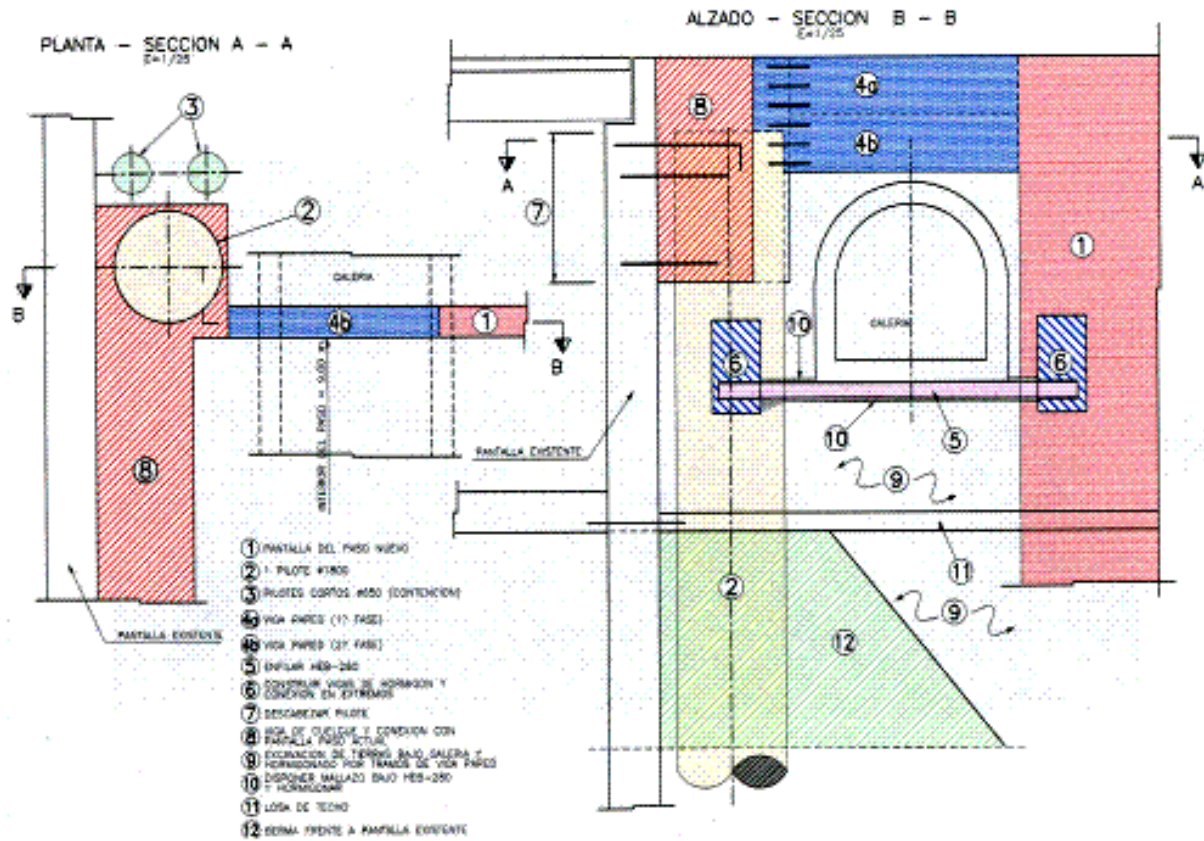


Figure 8. Supporting service galleries.



Figure 9. West entrance of the tunnel.

For the construction of the branches of the link with Alcalde Sainz de Baranda Street, it proceeded firstly to the excavation of the foundation zone of the prefabricated walls, as well as the abutments and the central support of the bridge, in the intersection with Alcalde Sainz de Baranda Street. Next the piles, the coronation beams and the foundations of the retaining walls of the link to Alcalde Sainz de Baranda were constructed. Finally the post-tensioning of cables was carried at the end of the superstructure of the bridge, as well as the carrying out of the corresponding test of dynamical load.

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