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Urban tunnel in beach sand, Bilbao

J. R. Madinaveitia
Ingeniería para el Metro de Bilbao, S.A. 'IMEBISA', Spain

ABSTRACT: In Getxo, a residential town on the outskirts of Bilbao, the present railway line runs between the Las Arenas y Romo districts, effectively separating the two. An urban tunnel of just over a kilometre is now being built to overcome this problem. The tunnel runs through beach sand with a water table very close to the surface. The solution involved constructing concrete diaphragm walls to form the two sides of the tunnel and Jet-Grouting to make a pre-bedding at invert level. The presence in some zones of organic material and even the remains of a sunken barge at jet treatment level caused major difficulties during construction.

1 FROM BARRIER ISLAND TO SUBURB: THE STORY OF LAS ARENAS.

The Nervión is a tidal river that winds its way through the city of Bilbao before emptying into the Bay of Biscay on the Atlantic coast, 15 km further downstream.

The river port gained a name in Europe starting in 1877, when the iron ore used in local foundries began to be mined on an industrial scale for shipment to the iron and steel mills of England.

Where it flowed into the sea, the Nervión was flanked by two mason-work wharfs with a 160 metre-wide channel running in between. Off to the one side, a mobile barrier island whose position changed depending on storms and tides made navigation in the area perilous to say the least. Running perpendicular to the flow of shipping traffic, it would frequently change locations in a matter of hours as a result of the tides. Apart from its instability, the prevailing winds buffeting the Atlantic coast provided an additional hazard.

Up on the left bank, clustering round its church, the village of Portugalete looked down on the mouth of the Nervión and the small dock that permitted vessels to load and unload in good weather, in open competition with the wharfs of Bilbao. The right bank, however, was the land of the barrier island, with its backwash winding between the dunes at low tide.

Plans for upgrading the wharfs of the Port of Bilbao included studies for improving the barrier island area, because this was the key to the future and safety of all maritime traffic.

In addition, in order to connect the river docks with inland trade, plans were drawn up for laying railway lines, initially seen as mostly for freight trains.

Soon, however, passenger lines were being promoted, and by 1893 a train was running down the length of the right bank of the Nervión from Bilbao to Plentzia, 30 km away, stopping at all the villages in between.

Prior to 1877, the year in which iron ore began to be mined on an industrial scale, such a railway project would have been unthinkable due to the lack of settlements in the area. In a mere 15 years, Bilbao and all the villages down to the coast had seen their populations multiply as a result of the industrial revolution.

Another area that gradually began to be populated was the barrier island partially closing off the right bank of the river mouth. The new inhabitants of the area also began to settle and protect the dunes, channeling the backwash into one stream, the Gobela river, and building a breakwater and outer wharf to finally bring the bar under control.

This settlement on the dunes of the river mouth is the suburb known today as Las Arenas. With a population of over 50,000, the area's train linking it to Bilbao was integrated into Line 1 of the city's Metro or underground transit system, inaugurated November 11, 1995.

In order to eliminate the traffic barrier posed by street-level tracks, the adaptation project called for the laying of approximately one kilometre of underground track and the building of an underground station.

The subject of this paper, then, is to present the preliminary ideas, design criteria and construction techniques applied to the execution of this project, which was carried out in beach sand and at close-to-surface water table levels.

2 BURYING THE EXISTING RAIL LINE

The initial idea was quite simple, and consisted of relaying the tracks under the axis of a street running parallel to the original line, and building an underground central platform station with street access from both ends. Finally, the tracks project included two ramps with a grade of 30 millesimals, whose final third would be covered. This design eliminated the traffic barrier posed by the old station and heightened the centrality of the new one.

The construction solution was also conceptually simple, as will be described in greater detail below, and the decision to lay the new tracks in a street parallel to the existing line made it possible to keep the trains running while the new facilities were being built.

3 GEOTECHNICAL CHARACTERISTICS

The recent geological history of Las Arenas provides clear evidence of the type of land concerned. Accordingly, few surprises were found in the preliminary studies, as it was well known that until a century ago, the area was made up of dunes and the low-tide backwash of a barrier island.

The ground was made up of sand, fine sand with lenticular layers of silt (Fig. 1). As expected, the geologists found small percentages of random organic material as a result of the riverside vegetation still to be seen today next to the Gobela river.

A sorry surprise, however, was the discovery of layers of wood some four metres below the water table, which as it turned out belonged to the remains of a sunken barge, most probably carrying coal.

This unexpected discovery was made during construction, as the borings executed during the geotechnical study failed to detect it.

4 TUNNEL EXCAVATION SEQUENCES.

The construction work was carried out according to the following sequences: (Fig. 2)

a) Delimitation of the outside perimeter with diaphragm walls.

Starting at street level, two reinforced concrete diaphragm walls were built measuring 0.8 m in thickness and 10 m in length, encompassing an inside area measuring 7.9 m in width, widening out to 14.5 m in the station area.

The walls were built in 3 m staggered modules with specially treated seams to ensure impermeability.

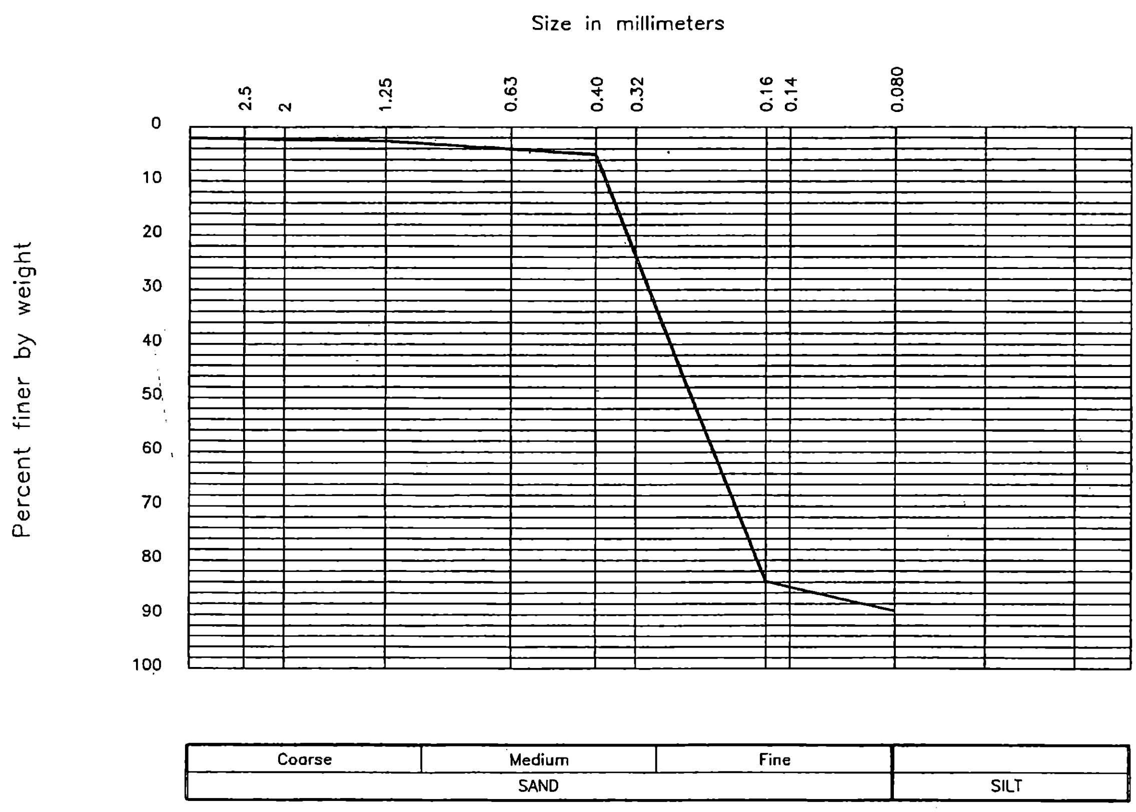

Figure 1

b) Ground treatment beneath invert level

As the water table was a mere 1.5 m below street level, and since the ground sands were highly permeable, it was necessary to treat the bottom of the future excavation in order to achieve, at least temporarily, two goals:

1. To create a bracing at the foot of the walls so that the inside space could be excavated without causing the top or bottom of the wall to move.
2. To seal off the floor of the excavated site and ensure its drainage without risk of siphoning.

The solution adopted consisted of jet grouting as ground treatment, according to the following parametres:

- Distance between column axes 1.2 m
- Dosage density 1600 kg cement/m3
- Water pressure 450 kg/cm2
- Cement pressure 15 kg/cm2
- Rotation speed 8-10 r.p.m.
- Build-up rate 8 min/ml

Work began using these parametres, but in certain areas difficulties were encountered in getting the mesh to close, as shown by the test borings. A direct relation was demonstrated between the presence of organic matter and the diameter of the treated column, which shrank from 1.4 m in clean sand to less than a metre in dirty sand.

The treated ground measured at least 2 m, a thickness that increased to 3.10 m in the station area,

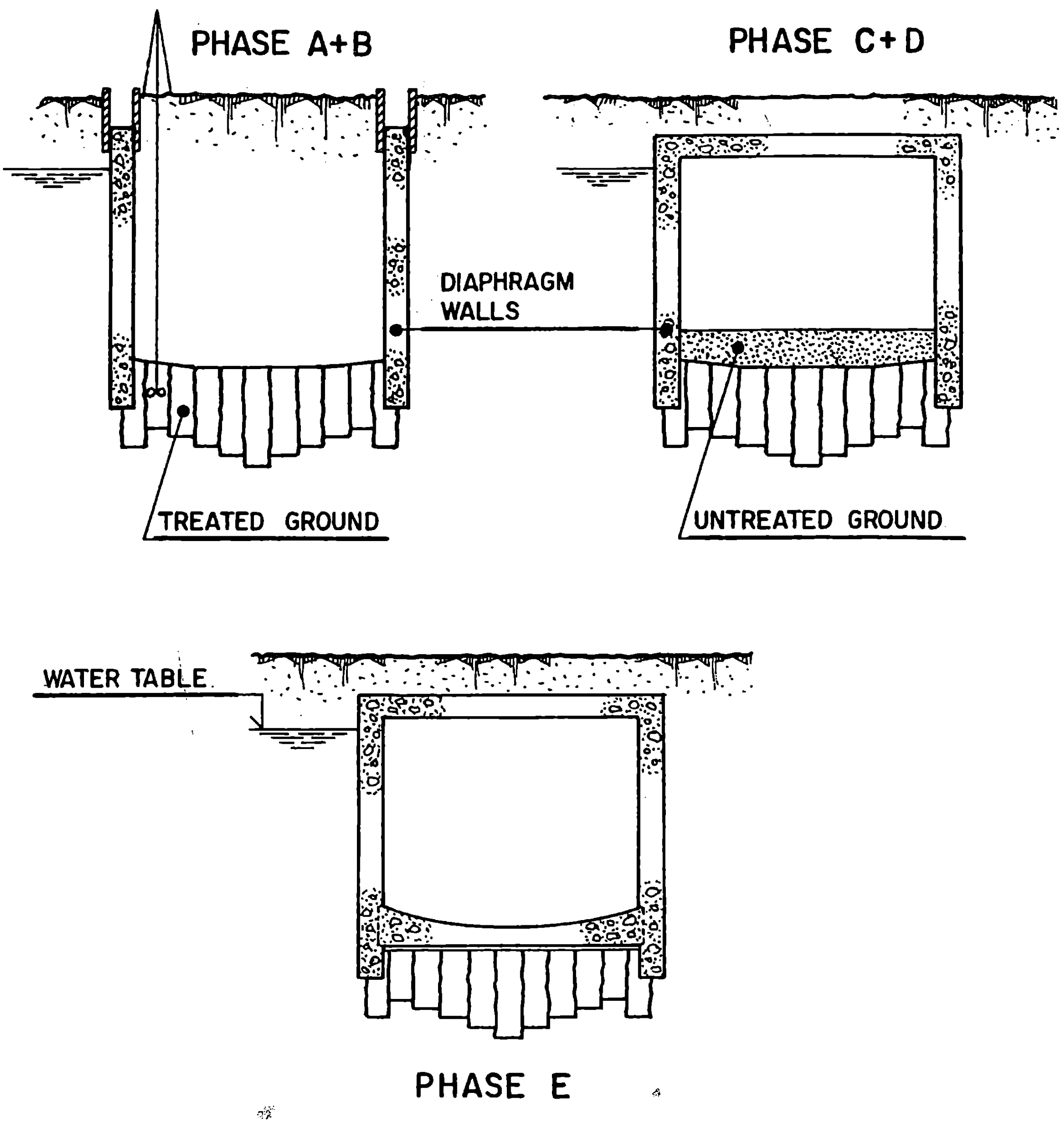

Figure 2

where the width of the space to be excavated between walls was greater.

c) Crown slab concreting

First the ground was excavated above the water table. A plastic sheet was then laid and the concrete poured directly to form the crown. This meant that the street could be restored to its initial condition in a very short time, thus inconveniencing citizens and traffic as little as possible.

d) Enclosure excavation

Before excavation could begin, the water remaining in the enclosure had to be pumped out. This was done by building drainage wells approximately every 50 m.

These wells, which were made of perforated pipe sunk vertically into the sand, permitted dry excavation of the tunnel.

So as not to interfere with the layer of ground treated with jet grouting, the general excavation level was set at approximately one metre above the definitive excavation level. During this sequence, no special problems arose, and the treatment was shown to have achieved the desired effects — a high degree of impermeability and the bracing of the wall foot. Only very small water infiltrations and wall movements were detected in daily monitorings.

e) Invert concreting

This was the most delicate sequence, since although only partially and for short periods of time, the treated ground had to serve as an arch subjected to an underpressure of 1 t/m2.

Work went ahead in 12 m stretches, excavating the natural soil that had still not been excavated, before arriving at the treated ground. To facilitate collection of infiltrated water, a thin layer of gravel was laid plus a layer of impermeable material. The invert was then concreted and structural continuity with the walls achieved by executing a hollow.

During this sequence water spouted at different points due to isolated faults in the treatment. The procedure devised for controlling them consisted of the immediate pouring of gravel to avoid siphoning and the sinking of a vertical Ø 2 inch pipe to channel off the infiltrated water. The end of this pipe was above the invert level and was fitted with a shutoff valve, channelling the flow of water through a conduit to the nearest drainage well. (Fig. 3)

The concrete slabs were spotted here and there with these pipes, which at certain points alleviated underpressure in the areas where the treatment had been defective.

Finally, the pipes were used to inject a cement plug which restored the tunnel floor to design conditions.

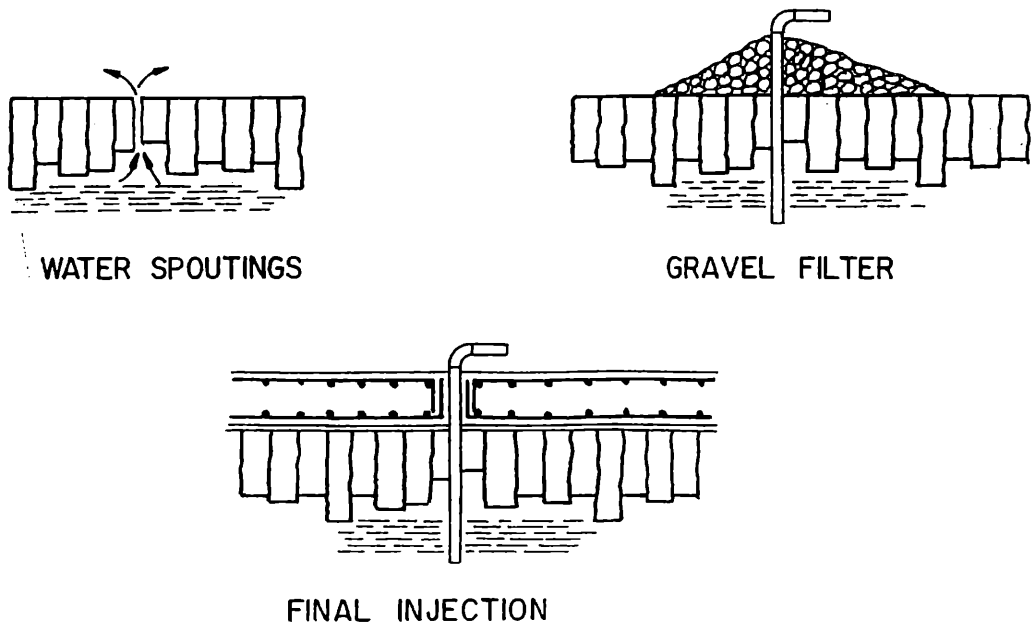

Figure 3

5 A WRECK

The first signs of the presence of wreckage buried in the excavation area were the abnormal consumptions of cement registered during the jet grouting work.

During treatment quality checks and tests, samples were taken with borings which demonstrated the presence of worked and assembled wood. These remains were finally identified as the hull of a barge of the type that so often plied the waters of the Nervión during the last century.

Once its possible archaeological interest was discarded following a study of the samples obtained, it was clear that the presence of wood at treatment levels would impede the homogeneity required. Accordingly, the mesh was closed with the execution of 1.04 m columns and a simultaneous increase in the density of the dosage, which in some cases reached as high as 2000 kg of cement per cubic metre treated.

Even so, the efficiency of the treatment remained doubtful at certain points. So, during the execution of sequence d) described above, supplementary injections were made in the area of the wreckage.

6 CONCLUSION

The jet grouting technique made it possible to build a cut and cover tunnel in beach sand with a water table very close to the surface.

Although water spouted frequently through the treated ground, the problem was controlled without siphoning of sand or settling on the outside of the tunnel due to the lowering of the water table, which was constantly monitored using piezometers.

The remains of a shipwreck at treatment level made it necessary to execute a denser mesh and supplementary injections. In the end, however, its presence proved to be little more than just another anecdote of the many that occur during construction.