Soil improvement with jet grouting for interconnection tunnels

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ABSTRACT
The “La Caldera” pumping plant project has an installed power of 40 $m^3/_s$. It pumps residual and pluvial waters from the Río de la Compañía tunnel into the Río de la Compañía channel, along which the liquid flows by gravity towards the Texcoco ex-lake. Generally speaking, the pumping plant consists of a Grid Shaft (Shaft 4 of the Río de la Compañía tunnel), connected to two pumping Shafts (Cárcamo 1 and Cárcamo 2) through two interconnecting tunnels, each with 5.0 m final diameter. As an alternative to the conventional system originally proposed for the construction of these tunnels (driven metal pipes), a new construction method was proposed and justified: the excavation of both tunnels by conventional methods, even in soft clayey soil, with the previous construction of two beds of soil improved by Jet-Grouting located between the Grid Shafts and the Cárcamos, all along the tunnels. In relation to the Jet Grouting, this document describes the works of the testing panel, its conclusions and the execution process of the definitive soil beds.

RESUMEN
El Proyecto de la Planta de Bombeo “La Caldera” tiene una potencia instalada para un gasto de bombeo de 40 $m^3/_s$. Su objetivo es desalojar las aguas residuales y pluviales provenientes del túnel Río de la Compañía al canal del mismo nombre para que fluya por gravedad hacia el ex-lago de Texcoco. De forma general, la Planta de Bombeo está integrada por una lumbrera de rejillas (Lumbrera 4 del túnel Río de la Compañía), conectada a dos cárcamos de bombeo (Cárcamo 1 y Cárcamo 2) a través de dos túneles de interconexión de 5.0 m de diámetro interior final. Como una alternativa al sistema originalmente propuesto para la construcción de dichos túneles de interconexión (hincado convencional de tubos metálicos), se presentó y justificó una alternativa novedosa de construcción, la cual consistió en la excavación de los túneles mediante método convencional, aun siendo suelos arcillosos blandos, previa construcción de dos macizos de suelo mejorado a base de Jet Grouting, en la zona entre lumbrera de rejillas y cárcamos, a todo lo largo de los túneles. Relacionado al Jet Grouting, el trabajo que se presenta describe los trabajos del panel de prueba, las conclusiones del mismo y el proceso de ejecución de los macizos definitivos.

1 INTRODUCTION

Construction of the pumping plant began in October-November 2009, and operations with one of the pumping Shafts began in June 2010, with operation at 100 per cent programmed for the same year’s last quarter. The plant is located at Ixtapaluca, State of Mexico –see Figure 1.

Figure 1. Location of Pumping Plant

1.1 Construction of pumping Shafts

The pumping Shafts were built using a circular structural diaphragm wall of 1.0 m thickness, 21 m internal diameter, starting at -41 m as a structural wall and continuing to -46 m as a screen in non-reinforcing concrete to reduce the risk of bottom failure (CONIISA 2009). Taking into account the fact that the pumping plant is located in a zone of stress-formed cracks from regional sinking (Auvinet 2009), prior to the diaphragm wall a soil treatment was carried out based on grout injections by gravity to seal possible cracks. The injections were located on the wall’s axis and on the river’s right bank near the Shafts. Excavation depth was 36.7 m, with the excavation for the core done in a dry, continuous sequence. To reduce pore pressures and thus the risk of failure by under-pressure, 12 relief deep wells were built in order to maintain and control piezometric levels. Figure 2 shows the location of Shaft 4 and the pumping Shafts.

1.2 Interconnection tunnels

The connection between the Grid Shaft (Shaft 4) and the pumping Shafts were made by means of tunnels of 5.0 m final diameter. The excavation procedure for the interconnection tunnels by means of conventional methods generally consisted of the prior construction of two soil beds improved with Jet Grouting, at the zones between the Grid Shaft and the pumping Shafts, the entire length of the tunnels, followed by a conventional excavation of the tunnels, together with the placement of a shotcrete based primary lining, and the posterior definitive lining.

Figure 2. Distribution of the pumping plant

2 GEOTECHNICAL MODEL (CONIISA 2009)

2.1 Stratigraphic sequence

- From 0 to 2.0 m depth we have the surface layer formed by clays and sandy mud of medium consistency, with natural water content average of 40% and 10 blows in standard penetration N_{SPT}.
- From 2.0 to 7.0 m, we have a high plasticity mud (MH) of medium to hard consistency, with some sand, with average w of 150% and N_{SPT} of 10.
- From 7.0 to 11.0 m, there is high plasticity clay (CH) of soft to medium consistency, with average w 200% and N_{SPT} of 7.
- From 11.0 to 16.0 m, we have a high plasticity mud (MH), of medium consistency, with some sand, with average w of 40% and N_{SPT} of 10.
- From 16.0 to 25.0 m, we have a high plasticity clay (CH) of soft to medium consistency, with average w of 130% and N_{SPT} of 4.
- From 25.0 to 34.0 m, we have a low plasticity mud (ML) of mid consistency, with average w of 50% and N_{SPT} of 8.
- From 34.0 to 52.0m, there is a high plasticity clay (CH) of soft to hard consistency, with some sand, with average w of 110% and N_{SPT} of 15.
- From 52.0 to 55.0m, we have a low plasticity sandy mud (ML) of hard consistency, with average w of 30% and N_{SPT} of 50.
- From 55.0 to 60.0m (maximum depth explored), we have low plasticity sandy clay (CL) of hard consistency, with average w of 90% and N_{SPT} of 25.

2.2 Hydraulic conditions in the soil's mass

According to the field works, the freatic water level (NAF) was detected at -9.60 m. As per the records of the piezometers installed on site, there is a very important abatement of hydraulic pressures, mainly from 33 m depth approximately.

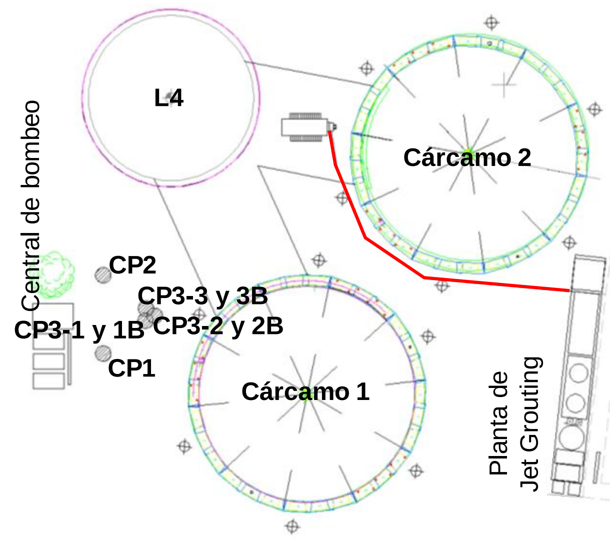
3 TEST PANEL

Considering a proper practice in the execution of massive improvement procedures for soils based on Jet Grouting (Morey J. 1992), before starting the construction works for the beds a test panel was designed and executed to determine through it the definitive execution parameters.

3.1 Location of test site and installations

The test columns (CP-1, CP-2 y CP-3) were located as close as possible to the Jet Grouting beds to be carried out –see Figure 3.

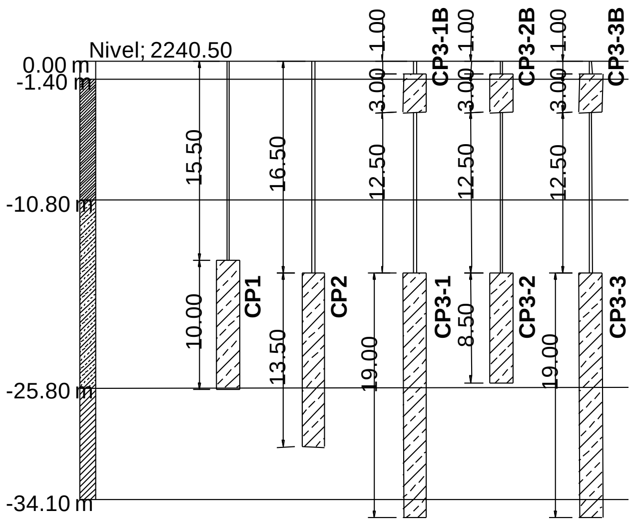
Figure 3. Floor plan view of location of test columns and installations to execute the Jet Grouting works



3.2 Description of the tests

Eight columns of various lengths were carried out. Two columns (CP1 and CP2) were built isolated. Three columns were built overlapping to the depth of the treated bed (CP3-1, CP3-2 and CP3-3), and three more (CP3-1B, CP3-2B and CP3-3B) were built overlapping but superficially. The superficial columns were exhumed afterward and their diameter was measured –see Figure 4.

Figure 4. Cross section of location of test columns



The first columns to be executed were CP1 and CP2. They were built in order to bring the operating methodology to point: drilling method, spoil handling, grout manufacture, operation of injection equipment, and selection of initial parameters for pre-Jet and Jet Grouting.

In all these tests we observed adequate spoils handling.

Along the execution of the tests, the following parameters were varied: number and diameter of nozzles, speed of descent (VD), speed of ascent (VA), rotation (Rot), flow volume (Q) and pressure (P), for Pre-Jet and Jet Grouting.

In all cases an injection mixture of water:cement was used, but in different proportions. Samples of the injection mixtures were taken to learn of their resistance to simple compression f'c at 28 days. Parameter f'c of the soil:grout mixture defined per project was of 10 kg/cm2 and the samples for testing came from the spoil generated during the Jet Grouting, which represents the improved bed material –see Figure 5.

All the resistance test results exceeded the design resistance.

3.3 Conclusions of the test panel

For the test results to be representative, the same constructive method defined for the definitive columns was used. That method consists of the following steps:

1) Drilling to the maximum depth.

2) Descendant pre-cutting (Pre-Jet) with air and water, from the top part of the columns.

3) Execution of the ascending Jet Grouting with air and injection mixture.

Figure 5. “Spoil” or rejection material

With the tests carried out, an adequate rejection of spoil materials during the Pre-Jet and Jet Grouting stages was proven, which indicated that there would be no significant increase in the land's lateral push.

Based on the measurements made at test columns CP3-1B, CP3-2B and CP3-3B, the possibility of making the columns of up to 2.0 m diameter was determined. The definitive distribution of columns was based on this information.

It was determined to start the works using an injection mixture with 700 kg of cement for 775 lt. of water, for which we obtained a resistance to simple compression (soil:grout) f'c at 28 days of between 16 and 51 kg/cm^2 with an average of 38 kg/cm2.

4 EXECUTION OF JET GROUTING BEDS

Figure 6 shows the distribution of Jet Grouting columns for each improved soil bed. Bed 1 between L4 and pumping Shaft 1 was formed with 54 columns; bed 2 between L4 and pumping Shaft 2 was formed with 49 columns, with theoretical diameters between 1.8 and 2.0 m for the softest clayey soils found at the depth of the Jet-Grouting beds.

The execution sequence was based on primary columns “P”, secondary columns “S”, tertiary columns “T”, quaternary columns “Q” and closing columns “C”, defined in terms of the moment of execution, to look for the proper overlap between them.

Figure 7 shows the location of the improved soil zone, with respect to the location of the tunnels. The bed's dimensions were defined considering the zone of influence of the excavation of each tunnel, and their superimposing, due to the possible simultaneity in the excavation. With the grout's resistance we also considered the possible lack of column overlap, due to drilling deviations from the vertical line and loss of energy at depth.

Figure 6. Floor plan view of the Jet Grouting columns

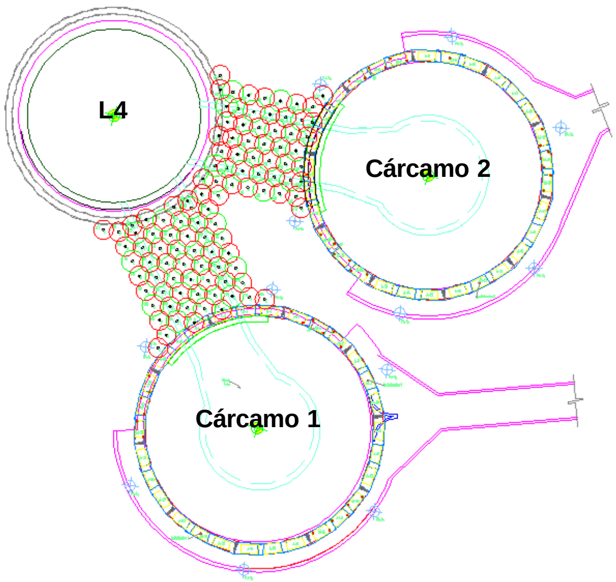
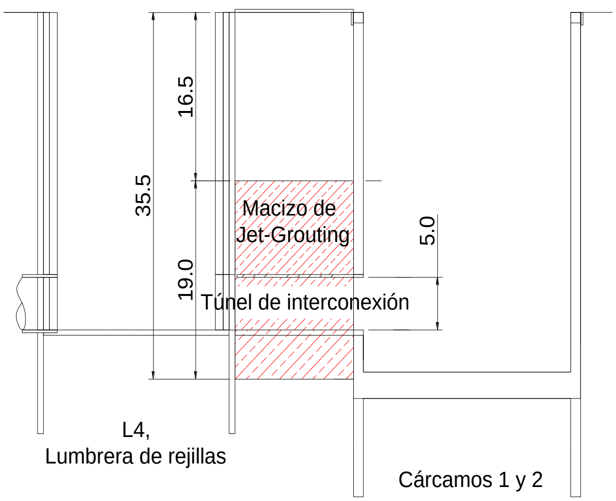


Figure 7. Cross section of the location of the Jet Grouting bed with respect to the interconnection tunnels



4.1 Controls to carry out during the tests

The controls carried out during the construction of the columns are described.

4.1.1 Instrumentation and tests

The execution was followed up by means of equipment, testing and the following procedures:

- Control and recording of drilling parameters and Jet Grouting mounted on the driller.
- High pressure (water and grout) and low pressure (air) manometers mounted on the driller.
- Air volume flow meter mounted on the driller.
- Water /grout volume flow meter mounted at high pressure pump's entrance.
- Baroid balance to measure grout density.
- Measuring system for the density of Jet Grouting spoils that come out of the drilling nozzles during construction of the spoils columns; the system consists of measuring the weight of a known volume of soil-cement mixture.

4.1.2 Control of the grouting dosage

Dosage of the water:cement grout is proven through the grout's density. This density is measured at the manufacturing plant with a Baroid balance. A larger control of the grout dosage was foreseen through at least density measurements per column.

4.1.3 Control of the soil cement mixture spoils

The spoils' density was measured directly beside the driller –see Figure 8- by means of a commercial balance with calibrated containers. The frequency of density measurements of the spoils varied and was determined at the work site by the responsible engineer in terms of the development of the works.

Figure 8. Execution of Jet Grouting columns and spoil collection pit

With a sampling of the soil:cement mixture that comes out to the surface the resistance to simple compression of the mixed material was controlled and followed during the execution of the columns (Jet phase spoils) at 7, 14 and 28 days.

4.2 Resistance and execution parameters

The average resistance to simple compression at 28 days for the soil:grouting mixture was 46 kg/cm^2, for an average resistance of the grouting (water:cement) of 143 kg/cm^2.

Columns of 1.8 and 2.0 m diameters were formed in the soft consistency clays. The parameters used during the Pre Jet stage in both cases were: VD=37.5 cm/min, Rot=15 rpm, Q=260 lt/min, P=250 bar, pass=2.5 cm and duration=4 seconds.

For the Jet Grouting stage there were two types of parameters, one for columns of 1.8 m and another for the columns of 2.0 m. In the case of the 1.8 m diameter columns: VA=18.8 cm/min, Rot=5 rpm, Q=210 lt/min, P=250 bar, pass=2.5 cm and duration=8 seconds. For the columns of 2.0 m diameter: VA=12.5 cm/min, Rot=7.5 rpm; Q=210 lt/min, P=250 bar, pass=2.5 cm and duration=12 seconds. Two nozzles of 3.5 mm diameter were used at all times.

Figure 9. Jet Grouting columns in tunnel code. The metallic frames formed by an IPR section of 12x8" (74 kg/m), ASTM A36, separated every 2.0 m can be seen

5 CONVENTIONAL EXCAVATION OF THE TUNNELS

Figure 9 shows the improved soil columns located in the tunnel's code, with their superimposing, and also zones of soil not mixed with the grouting, although the soil located between columns improved its resistance notoriously, a priori due to the possible loss of water from the heat generated by the setting of the grouting-soil. This increase of resistance is a subjective appreciation upon touching.

The possibility of the columns' lack of "superimposing" overlap was considered through the grout's specified resistance. The lack of overlap is due to the drilling's deviation from the vertical, the occasional presence of soils of firm consistency and shadow zones. Such possible overlap failures were considered by the specialists from the start of the project, but the situation was not considered critical, because of the fact that there was no risk of a plastic flow of fine soils with very low permeability in the soil zones to be treated.

As a construction sequence, first one of the tunnels was excavated and coated and after those works were concluded, the second tunnel was excavated and coated.

Figure 10. Excavation of one of the interconnection tunnels, with conventional procedure. The metallic frames placed for the excavation's safety stand out

The change of the soil's mechanical properties with the application of Jet Grouting was notorious. In fact, the excavation was carried out practically without immediate placing of the shotcrete-based temporal lining, though for safety reasons in the excavation, metallic frames wedged with wood were installed –see Figure 10.

6 CONCLUSIONS

Applied to soft clayey soils, with little resistance and important treatment depths (more than 30 m), a massive soil improvement was designed and executed based on the application of the Jet Grouting technique. The application of this alternative technique, as opposed to conventional pipe driving procedures, allowed reducing the construction times in an important manner, and carrying out a conventional excavation under safety conditions, to successfully conclude the interconnection tunnels between the pumping Shafts.

Prior to the execution of the works, the design, implementation and interpretation of a test panel became necessary, with which the definitive execution parameters for the Jet Grouting were defined. This is a practice that should be adopted in this type of massive soil improvement technique.

7 REFERENCES

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