Grouting solutions for urban transport problems

In the Ecuadorian capital of Quito, one of the highest metro systems in the world is currently being built. The first line will run for over 22km through the city at an altitude of more than 2,800m above sea level

A Comacchio MC 30 rig performing jet grouting along the densely populated Pinllopata and Rumichaca street, in the southern part of Quito

Nestled in a narrow 40km-long valley, 2,800m above sea level and surrounded by the Andes mountains, Ecuador's capital city, Quito, is experiencing major traffic congestion leading to an increased demand for public transportation. To address the city's transport problems, a project is underway to build a 22.5km subway system, which will run from Quitumbe bus terminal in the south of the capital to the Mariscal Sucre Airport in the north.

Once completed the new metro line will have 15 underground stations with trains running at 37kph for a journey time of 34 minutes between the two end terminals. The stations along the route will connect the busiest areas of the capital and allow passengers to transfer to other modes of transportation, such as local bus services. The metro will operate six-car trains, capable of accommodating up to 1,500 passengers, with a total capacity of 400,000 passengers per day.

The project, funded and instigated by the municipality of Quito and the Ecuadorian government, with financing from international institutions including the Development Bank of Latin America, the Inter-American Development Bank, the World Bank and the European Investment Bank, has been assigned to the consortium Línea 1, which is comprised of civil engineering contractors Acciona Construcciones (Spain), Acciona Industrial and Acciona Infraestructura México, with the Spanish consortium GMQ as technical advisor. The estimated cost of the project is €1.3 billion (US$1.5 billion) and it is expected to generate 3,000 construction jobs and 800 permanent jobs.

PROJECT PHASES

The initial plans to construct a metro for the city of Quito were put forward in March 2009 with feasibility studies for the project starting in October 2010 and completed less than a year later in June 2011. The engineering design for Line 1 was then completed by May 2012.

Construction work on what became known as the Metro de Quito Line 1 began in January 2013 and is being done in two phases. Phase one, successfully completed in 2015, involved the construction of two stations at La Magdalena and El Labrador. Phase 2 of the project, which began in November 2015, involves tunnelling works to lay the track for the entire 22.5km of the route and the construction of the remaining 13 stations at distances of between 1.0 and 1.8km each. Two tunnel boring machines (TBM) are expected to be used for the tunnelling works under Phase 2, with tunnel depth varying between 15 and 26m. Construction is expected to take 36 months, with a further six months for systems integration and commissioning.

PROJECT GEOLOGY

The project posed significant financial and technical challenges, with the latter having to be addressed because the city is located in a region of high seismic activity. The geological and geotechnical characterisation of the soil, on which Quito is built, was done as an integral part of the construction of the metro and constitutes the first integral study of the geology of the city. It was based on surveys carried out in Quito since 1940, information to which all the support studies carried out since 2011 have been added.

An extensive soil survey campaign under the supervision of experts from Metro of Madrid was undertaken, which involved the execution of 70 boreholes along the metro line route (equating to a total amount of over 2,800 drilled metres). This meant one survey every 300m and two surveys per station to a depth of 20 to 30 additional metres with respect to the maximum excavation level.

The campaign required the use of a vast number of geological research techniques, some of which were applied for the first time in Ecuador in urban areas. The survey included a study of the structures of the buildings located along the metro route, as the tunnels run through the densely populated city centre, that has been declared a World Heritage Site by UNESCO.

The terrain crossed by the tunnel mostly consists of sedimentary soils of volcanic origin with different degrees of compactness (Cangahua formation). The route also crosses low resistance areas made of anthropic landfill and soft clays. The superficial strata of the area tend to deform, so it was necessary to design areas for ground treatment and improvement in order to minimise surface settlements and protect the most vulnerable and historic structures.

GROUND IMPROVEMENT

The Línea 1 consortium awarded the contract for the ground improvement program to the Spanish-based international construction collective Terratest Group. The program consists mainly of micropile slurry walls and umbrellas, extensive treatment with jet grouting and compensation grouting.

The installation of micropiles is being carried out both on the surface, for the construction of slurry wall retaining systems for the buildings located along the tunnel alignment and inside the underground stations for the installation of umbrella pipes for the tunnel openings. Comacchio MC 800 (MC 12) and MC 1200 (MC 22) drill rigs are being utilised in this part of the project. The plan is to use them to install a total of 167,584m of micropiles, with diameters ranging from 140 to 350mm within a period of 13 months.

Jet grouting is being used for the improvement of less cohesive soils and/or anthropic landfills, at the entrance and exit shafts of the tunnel boring machine at the stations and to create waterproofing cut-off walls and water sealing bottom slabs. The use of a multi-fluid system was selected to allow for the construction of jet grouted columns with over 1.5m diameter. A total of 101,899m of jet grouting are expected to be performed in a period of 23 months. Comacchio rigs MC 1500 (MC 30) and MC 1200 (MC 22) in jet grouting configuration were used to drill with 114mm rods at a depth ranging from 22 to 42m.

COMPENSATION GROUTING

Compensation grouting was undertaken to limit TBM induced settlements in several parts of the tunnel alignment, beneath the foundation of buildings located above the tunnel.
The aim of the treatment was to create a sub-horizontal layer of consolidated ground between the tunnel crown and the overlying structures, thus protecting buildings and other structures from movement that might cause damage. In order to execute the sub-horizontal grout injection, six shafts were excavated with a depth between 4 and 10m. The shafts were equipped with a working platform from which the treatment works were carried out.

The consolidated pillow of ground to be formed from these shafts consisted of a fan-shaped array of (steel pipe) tubes a manchette (TAM). This allowed for the ground to be proactively treated before, during and after the passage of the TBM, thanks to grout injections at controlled pressures.

The MC-S 12 is a special unit designed and built by Comacchio to perform TAM installation for compensation grouting inside shafts

Two Comacchio MC-S 12 units were utilised to perform TAM installation from the shafts. These units were specifically designed by Comacchio to meet the project requirement of Terratest Group. Each of the Comacchio rigs was installed on a rotating platform, allowing for drilling around the shaft perimeter and equipped with a skid-mounted separate power pack providing 86kW of power. The platform with the drill rig was fitted with hydraulic jacks that allowed it to operate at various heights inside the shaft. A total of 20,908m of TAM pipes were installed with rotary drilling technique using 152mm tooling.

Once the drilling and installation of the TAM pipes was completed, the grouting was performed using cement-bentonite grout. The grout mixture was selected to provide maximum stability and reduced sedimentation and facilitate repeated injection. Grout mix, injection pressure, volume and pump rate were carefully designed and computer monitored. Process control was accompanied by accurate monitoring of the movements.

Due to be completed by 2019, the Metro Line 1 is expected to accommodate approximately 369,000 passengers per day in its first year of operation and cater to 500,000 commuters by 2030. Plans to construct Lines 2, 3 and 4 are also being considered.