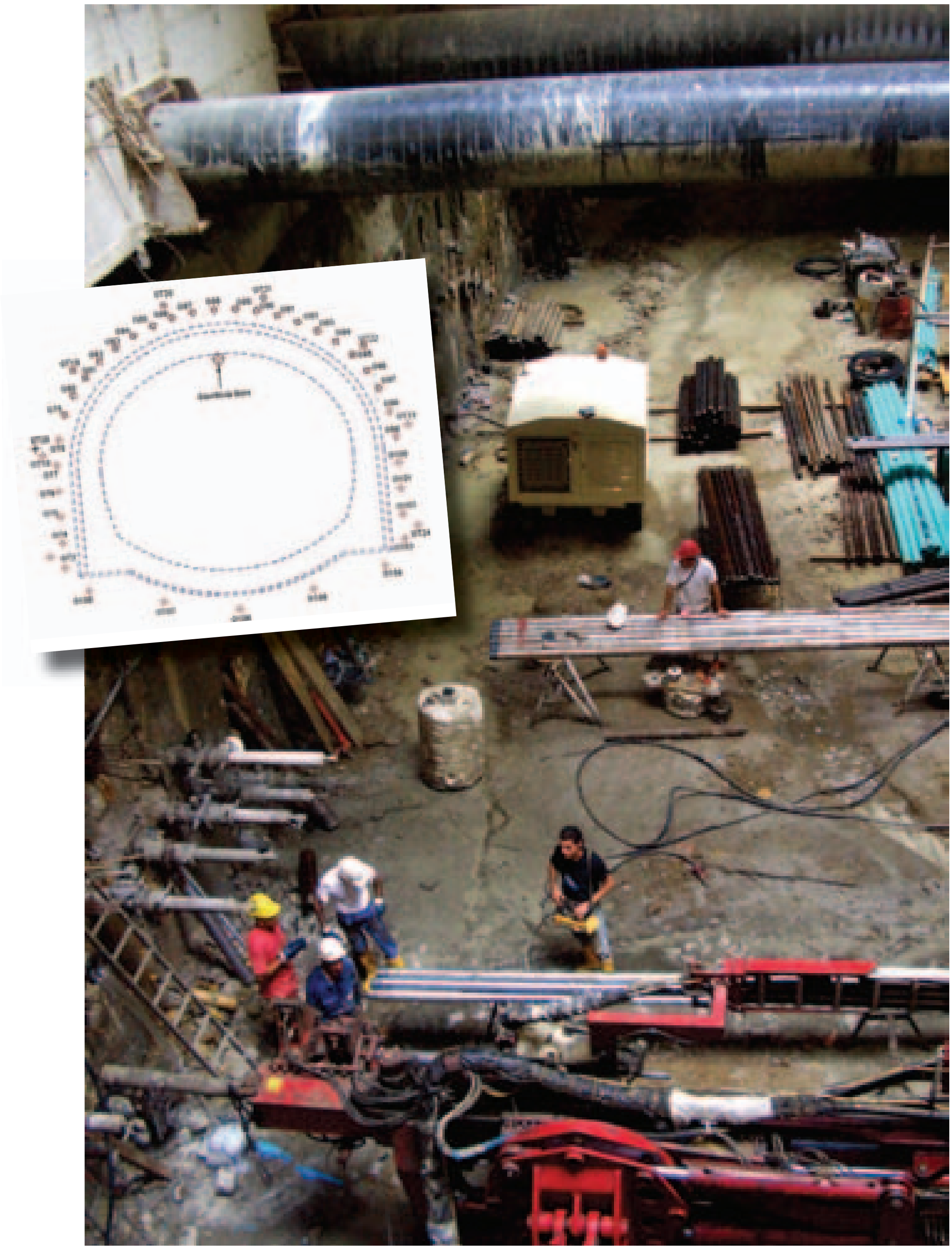
Trenchless trends help central Naples build metro station



Above: a site overview showing the large steel beams supporting the inner walls of the main access excavation. Inset left: A computer-aided design drawing showing the position of all boreholes around the outside of the gallery to be excavated. (Those boreholes marked with 'GT' are those to be used as temperature gauges)

'Trenchless' guidance and ground freezing combine to ensure accurate, and secure, excavation of the metro station under Naples' Piazza Garibaldi

AS PART of a continuing work programme to create an underground metro system in Naples, Italy, contractor Pizzarotti is undertaking a drilling operation to help develop the metro station at Piazza Garibaldi, opposite the mainline railway station in the city centre.

The project highlights the growing inter-dependence of traditional tunnelling technology and methods more commonly seen as 'trenchless' in nature. Work, which began in January 2002, is due for completion in March 2007.

Initially, the external underground walls for the station were excavated and filled with reinforced concrete. Once this was completed, excavation of the internal area could begin. Large supporting beams were required as the excavation grew deeper. Once at the required depth, the station excavations will be intersected by the train running tunnels, currently being constructed using a tunnel-boring machine. The space necessary for the passenger platforms at the stations will be extended beyond the station walls and underneath the piazza. Since two train lines will pass through the station, four 'galleries', two on each side of the station, are needed. It was decided to use ground-freezing techniques to excavate these much wider 'tunnels', so this required a pattern of boreholes to apply the ground-freezing fluids.

GROUND FREEZING

Ground freezing is sometimes used as a method of tunnel excavation where there is a large area to be excavated that lies well below the water table. It is achieved by creating a pattern of several close-proximity horizontal boreholes around the perimeter of the area to be excavated.

The water around these boreholes is then frozen by circulating concentrated brine (a saline solution) through the boreholes, at a temperature of about -35ºC. The pattern is designed to allow the frozen sections around individual boreholes to overlap, to 'seal', stabilise and separate the ground to be excavated from its surroundings.

In this instance, the ground temperature is measured during the freezing process using eight temperature gauges inserted through boreholes around the perimeter of the gallery. Once the surrounding area is frozen, the gallery interior can be excavated safely, with the surrounding ground pressure supported by the newly-created ice wall. The freezing process continues throughout the excavation period to ensure the ice wall remains solid.

Obviously, a project such as this requires the original freezing boreholes to be drilled to a very high accuracy, as any gaps in the ice wall could cause a collapse, which would be catastrophic.

BORE REQUIREMENTS

Trevi SA, a major Italian contractor specialising in foundations for large civil engineering projects, won the contract to construct these galleries using the freeze-drilling method.

The galleries were designed to be 50 m long using a protective ice wall of just 1.2 m thick. With the radius of ice produced around individual boreholes being only 0.6 m, the boreholes had to be completed to a high degree of accuracy. The traditional method of completing a project like this would be to complete each gallery in two sections, one 30 m long and the other 20 m, using unguided boreholes. This would have required a long set-up time because the pipes connecting to the freezing equipment would have to be installed, the ground frozen and excavated on the first section and then everything would need to be set up again for the second section. It would also be impossible to drill the boreholes for the second section in exactly the same direction as those of the first, because the drilling of the second section would be undertaken from within the confines of the first section, creating a problem in setting up the rig near the outer wall. Ideally, a method had to be found that would enable close-proximity drilling over the full 50 m length.

INITIAL ATTEMPTS

Initially, Trevi contracted an horizontal directional drilling (HDD) guidance company with the aim of deploying HDD guidance technology. This technology, developed over the past few years for

Above: the top half of one of the galleries before excavation with all but five of the holes in the section completed. These five are marked by square steel plates on the far left-hand side. The location of the sacrificial bore can just be seen in the centre of the gallery, about 1.5 m beneath the highest borehole

use in the directional drilling industry, is one of the most accurate and reliable methods of location and steering available for completing HDD projects.

The method uses an electronic probe mounted behind the drilling assembly, which relays information back to the surface using a wireline placed inside the drill pipe. The probe gives inclination and azimuth readings with the azimuth is read by a very sensitive and accurate onboard compass. It also reads the strength of the magnetic field surrounding the probe and the angle of the Earth's magnetic field at that point (known as the mag and dip, respectively). This information is used in conjunction with a surface wire of known dimensions, through which a current is passed. Using the known position of the wire, the probe is able to use the magnitude of the detected magnetic field, and the field's angle in relation to the probe to calculate the probe's position very accurately.

Usually the wire is deployed in a rectangular configuration, with one side of the rectangle passing over, or very close to, the alignment of the bore to be drilled, the 'centreline'. The other side, the 'return path', is kept at a distance large enough not to affect the readings measured from the centreline by the probe.

It was using this configuration that the initial guidance company attempted to deploy Paratrack-II. Unfortunately, the method was attempted in

Above: the pipe used to mount the coil. The indents down both sides were used to align the cable accurately along the coil's entire length

circumstances where the sheer volume of moving traffic on the piazza, compounded by a high volume of reinforced concrete on the construction site, created enough magnetic noise to cause lost signal and steering inaccuracies.

Even if data had been obtained within this downtown, major city environment, the distance of the borehole from the surface, about 30 m, would not have yielded high-enough accuracy to solve the customer's problem.

The only remaining option at the time seemed to be to position a wire underground in a way similar to that used for guiding parallel boreholes in the HDD industry. However, it was impossible to place a wire close enough and follow the drill path without excavating the gallery or drilling a borehole from entry to exit within the piazza perimeter. Clearly, this was not an option, and the initial guidance

Drilling in progress on one of the galleries using the 10 t EGT rig with 2 m-long drill pipes that had been pre-built into 9 m lengths to save time in making connections to the probe

contractor, having no further solutions, departed. It was at this point that Trevi contacted Netherlands-based Prime Horizontal.

INNOVATIVE SOLUTION

Prime Horizontal is a six-year co-developer of the Paratrack-II system with Vector Magnetics, which owns the technology. ParaTrack was initially developed for close-approach drilling in oil and gas fields and adapted for use in the HDD market. As a result, Prime Horizontal is an authority on deploying this system in all HDD applications.

Through extensive, controlled testing in the Prime Horizontal workshops in the Netherlands, it was discovered that it is possible to attain accurate results from a very narrow coil when the probe is in relatively close proximity. This gave rise to an interesting solution to the problem posed by the metro station project. A sacrificial borehole could be drilled through the middle of the galley and a narrow, 50 m-long coil placed inside. This coil could then be used to track all the surrounding boreholes of that gallery.

Several obstacles still had to be overcome. One of these was the signal strength. The electromagnetic (EM) field created by two wires alongside each other at zero separation carrying an equal current is cancelled.

Therefore, in a situation such as this, with the two paths of the coil being so close to each other, much of the EM field created by the closest wire is cancelled by the wire on the other side. Furthermore, the signal strength-to-distance ratio follows an 'inverse cube law'; doubling the distance from the source causes a reduction in field strength by a factor of eight.

Another problem was the down-the-hole orientation of the coil. With such a narrow coil, any slight deviation from a horizontal alignment would cause a relatively large error. Therefore, a method to accurately place the coil down-the-hole was devised by using a rigid plastic pipe with grooved markings to help attach and align the coil.

SUCCESS

Overall, this new method of deploying the Paratrack-II system, now known as the ParaTrack Micro-Coil, was considered an immediate success, saving time and expense for the contractor. The ease of setting-up and using the equipment meant that after a few weeks' instruction, the contractor, having had no previous experience in using such a system, was able to operate the Paratrack-II system entirely unaided. Trevi has since bought its own ParaTrack equipment.

Prime Horizontal, when consulted about a specific application, was, therefore, able to adapt an innovative and novel solution to a difficult guidance problem.

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ONSITE METHODOLOGY

It was decided that, for optimum results, a sacrificial bore would be drilled through the centre of each gallery to be constructed. This bore was to be drilled without any guidance tools and surveyed afterwards using a post-drilling survey tool called a Maxibore. This is an optical down-the-hole surveying probe about 5 m long that measures the flex along its length at predefined points in time to calculate the path travelled. For better accuracy, the sacrificial bores were also surveyed using the inclinometer on the ParaTrack-II probe to calculate the elevation.

After drilling the sacrificial bore, the Micro-Coil was carefully inserted. As mentioned above, any slight rotation of the coil down-the-hole would give relatively large errors, and so was to be avoided.

Once drilling began, it became apparent that the Micro-Coil was indeed an effective solution to the problem, even with the expected drop-off in signal strength as the distance to the sacrificial bore increased. This drop-off in signal strength was apparent in the observed increase of EM interference, which increased the time taken to make an accurate positional survey. The drilling time for those boreholes near the sacrificial hole was about three hours, while for those furthest away, a distance of 6 m from the sacrificial hole, the drilling time increased to around five hours.