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Recent uses of directional drilling technology in the construction field

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ABSTRACT: The increasing complexity of the modern projects requires a never ending process of innovation in the construction technologies. In fact, the constant need to improve the transportation networks in especially congested urban areas, entails the need of accurate technologies to cope with the increasing depth of excavation for underground structures. The improvement of the efficiency becomes therefore essential, to save time and money. As a result, the need to control the excavation process has become a must in most of the technologies involved in these projects. In recent years the use of the hydromill turned out to be fairly ordinary for the excavation of the deep shafts, where the compliance of tight tolerances is of paramount importance. The same tight tolerance is now required also for sub-horizontal drilling, when special technologies are used for drilling long holes. For this reason, the use of the HDD technology (Horizontal Directional Drilling) has been recently introduced also in geotechnical works. The paper summarizes some of these applications in recent projects of TREVI, as curvilinear holes necessary for the compensation grouting in Bologna High Speed Railway, or the installation of pilot holes for the construction of cut-off walls in the rehabilitation of dams in New Zealand and in United States. Then, the paper describes the latest application of this technology for the execution of long holes required for the sealing of the bottom in a dumping area in Manfredonia, Italy.

1 FOREWORD

The use of directional drilling has been for long time a privileged area for the oil industry, for the execution of “Christmas tree” wells to maximize the productivity from a single well neck.

Then, the gained experience was used to develop “river crossing” methods, especially for the installation of pipelines and underservices in crowded areas and/or difficult conditions. In turn, the same experience was then used for the so called trenchless market, where the Horizontal Directional Drilling (HDD in short) was used for the installation of pipelines in urban areas to avoid the open cut excavation for the installation of pipelines (Fig. 1).

In the present days the market of construction is becoming more and more competitive, and there is an increasing demand for high quality work, where this can lead to a reductions in the costs. It is a fact that by increasing the quality control, the “safety factor” can be reduced, as there are reliable measurements. As the Directional Drilling allows to measure and control every single hole, therefore the overdesign can be reduced to a minimum.

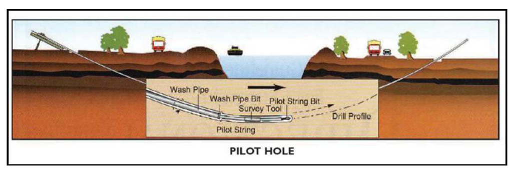

Figure 1. River crossing technology (typical).

The present paper describes the original application of the Directional Drilling in different projects for various purposes, demonstrating the big potential of this technology in the construction field.

2 PREVIOUS GEOTECHNICAL APPLICATIONS OF DIRECTIONAL DRILLING

TREVI introduced the use of the Directional drilling in first years of 2000 in a large project of

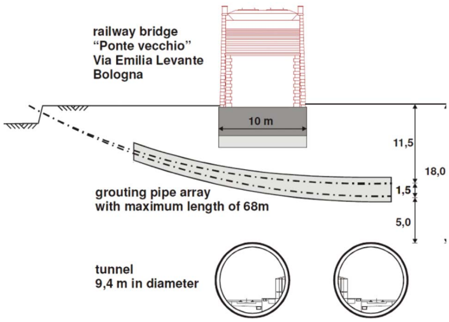

Figure 2. Via emilia bridge—compensation grouting.

the metro in Naples (line 1 Dante-Garibaldi) for three different stations. About 30,000 m boreholes in excess of 50 metres were successfully drilled for the installation of freezing pipes and thermometric probes. The selection of the directional drilling was dictated by the need to precisely install the freezing pipes with an accuracy of few centimetres.

The holes were drilled starting from shafts as deep as 40 m, with a water counter head of up to 30 m. The depth, the congested milieu, the presence of vehicles traffic and of the railway line added difficulty to the guidance system. In order to overcome the problem, after many tests, a new method making use of a micro-coil was invented and successfully used throughout the rest of the project.

In the same years, the directional drilling was used in two projects of compensation grouting in Bologna. The compensation grouting was necessary to concurrently control the settlements created under two brick bridges by the excavation of the TBM for the high speed railway passing underneath the existing common railway (Fig. 2). Since the congestion in the area and the tight schedule did not allow the original plan to excavate a shaft and drill the boreholes for the compensation grouting in a fan shape layer, it was proposed and agreed to drill the holes from the surface, therefore minimizing the impact to the existing activities in the vicinity.

Two layer of sub-horizontal holes were drilled for the installation of sleeved steel pipes at a depth of approximately 15 metre under road level. The hole were up to 65 metre long.

Both projects were successfully completed.

3 DIRECTIONAL DRILLING USED FOR REPARATION OF TOW DAMS

3.1 *Arapuni dam: a 95 metre deep cut-off wall*

In 2005 TREVI was invited to participate a tender for the reparation of the Arapuni dam in New Zealand. The 60 metre high, gravity concrete dam owned by Mighty River Power suffered since the beginning of seepage problems, due to a series of vertical fractures under in the dam foundation, with the presence of highly erodible joint infill that is vulnerable to piping erosion. This combined with nearlake pressure in areas under the dam due to open fractures in the ignimbrite rock foundation pose a risk of a major leak under the dam.

An extensive programme of investigative core drilling and detailed foundation mapping was completed to determine the extent and nature of the fissure systems. The investigation findings allowed partial cut-offs to be designed to specifically target each of four sets of identified vertical fractures.

Considering the difficulty of the job, the Client decided to form an Alliance with the Contractor.

The closed collaboration of the Alliance (Owner and Contractor) and the Designer (Damwatch of Wellington, NZ) allowed to select a method which suites the requirement of complete the project maintaining the reservoir fully operational.

Construction of the four overlapping bored pile walls consisted of 400 mm diameter holes drilled at 350 mm centres. The 95 m deep holes from the dam crest extend through the concrete dam and 40 to 60 m into the vertically jointed ignimbrite (Fig. 3).

In order to form a continuous wall with such tight tolerances, TREVI proposed to use an innovative method involving the use of directional drilling to form pilot holes, to be further reamed out to the design diameter. The pilot holes were drilled using a mud motor, followed by a patented special reverse circulation drilling system.

3.2 *Wolf Creek Dam: 1000 holes for 85 metre deep cut-off walls*

In 2008 the US Army Corps of the Engineers issued the tender for the installation of a 24-in thick (60 cm), 274 ft deep (84 metre) concrete positive cut off wall to stop the seepage under the Wolf Creek Dam, in Jamestown, KY.

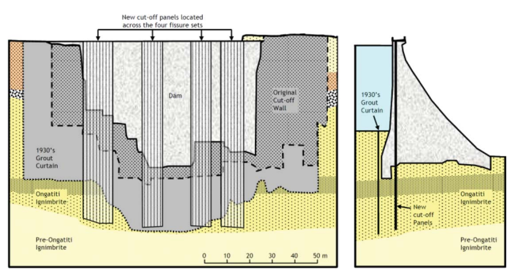

Figure 3. Arapuni cut-off wall (view and cross section).

The dam, built in the late 40's, is formed of a concrete section and an earth section, and suffered since the its birth of seepage under its foundation. The dolomitic karstic limestone is crossed by a large system of fissures and caves, and the danger of piping was underestimated at the time of construction.

After several sinkholes appeared downstream, the dam was repaired in the late 70's, by installing a positive cut off wall of secant piles.

However, in the time the instrumentation showed signs of distress, with high piezometric levels, and the COE decided to install a second cut-off wall upstream of the previous one.

The tight specification of the job, with a maximum deviation from verticality of 6 inches (150 mm) were judged suitable for the directional drilling, to duplicate the success of New Zealand.

It was therefore decided to install secant piles using reverse circulation to follow the pilot holes drilled with the directional drilling. The selected method allows to systematically control the deviation within the tolerances of the project.

The project will involve drilling up to 1000 holes, and its completion is due in 2013.

4 CONTAINEMENT OF TWO POLLUTED AREA IN MANFREDONIA, ITALY

In the hills close to the city of Manfredonia, in Apulia, southern Italy, it was discovered that two dumping sites needed to go under an important retrofitting work.

The two sites, called Conte di Troia and Pariti I-RSU (Fig. 4), were used in the past years to dispose industrial and urban wastes, backfilling the excavation of exploited calcarenite quarries and then capped.

The area is located on a gently sloping hill, and the two sites are separated by a gully called "Vallone di Mezzanotte", which originated from the Karstic—erosive activity on the bedrock (calcarenite and calcilutites limestone).

The uniaxial compressive strength ranges from 5 to 10 MPa for the calcareniti and 25 to 30 MPa for the calcilutites. Both rocks are deeply fractured. The water table is at the sea level, 50 m below the surface dump area.

Several campaign of soil investigation, together with environmental and hydro-geologic studies allowed to discover that no protection sheet was installed at the base of the dumping areas.

Particularly, in 2009, some samples have been collected from the base of the waste, and analyzed in laboratory. The result was that the fractured calcarenite at the base (Figs. 5 and 6) is sometimes clean and sometimes contaminated for few meters under the waste bottom, but there is no leachate. It has been supposed that the leachate generated from the drained water migrates to the below water table through the biggest fissures so that it cannot accumulate.

Therefore, to comply with the directive CEE 91/156, the installation of a containment is required to avoid hazards to the environment and to the water system. The project is under a dedicated Government Agency (Ufficio del Commissario Delegato per la bonifica di discariche pubbliche di Manfredonia OPCM n.3836/09).

Figure 4. Location of the two areas.

Figure 5. The calcarenite at the base of Conte di Troia.

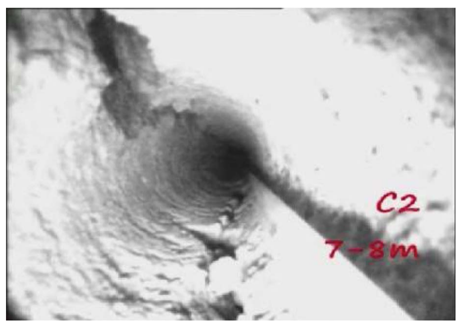

Figure 6. Borehole camera in corings, with evident fractures.

The Conte di Troia disposal area has a total surface of 25.454 m^2, and a perimeter of 780 m. The volume of the waste material is 140.000 m^3, and its maximum thickness is 16 m.

The surface of Pariti I-RSU is 19.600 m^2, and a perimeter of 660 m. The volume is 260.000 m^3, and its maximum thickness is 25 m (Fig. 7).

A first hypothesis was the removal of the wastes and the temporary relocation of the waste in a close by area, to allow the installation of the impermeable membrane to contain the waste as per the current regulation.

However, due to excess of time needed and the great volume of waste of uncertain nature to be moved (with all the related environmental risks) it was decided to design a solution of an in-situ containment. So a second project was designed with vertical impervious diaphragm walls on the perimeter and a grouted bottom plug carried out with a huge quantity (up to 25,000 holes for approximately 500,000 lm of drilling) of vertical boreholes crossing the total waste area to reach the calcarenite below to be treated.

But, obviously, also this second solution was affected by time and environmental risk problems. So the final designers (Sviluppo Italia and Sintesi) selected a very innovative solution foreseeing that the impervious bottom slab should be created by grouting the rock underneath the volume of the waste (as found by the soil investigation) by means of a double layer of sub horizontal curved directional drillings (Fig. 8).

The perimeters of the area should be contained in the same way by installing a cut-off wall with a triple row of sub-vertical holes.

In 2010 the public tender has been awarded to an ATI leaded by Cons. Coop. Costruzioni—Mucafer) with Trevi as specialist Sub-Contractor.

The works started immediately after the award, and involved several rigs and plants to cope with a tight schedule.

The bottom slabs of the two areas will be formed by a total of 565 holes, equal to 58,380 linear metre.

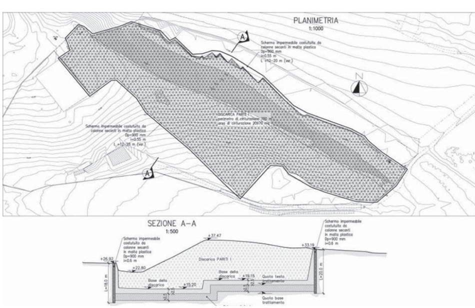

Figure 7. Pariti I-RSU, plan and cross section.

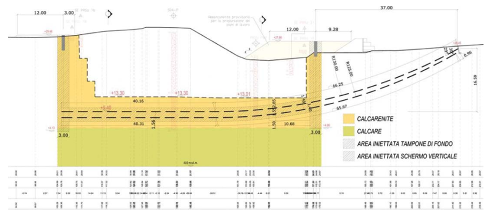

Figure 8. Bottom slab created by directional drilling.

Figure 9. Panoramic view of Conte di Troia site.

The average length is 103 m with a maximum of 150 m.

The holes are drilled using a surface magnetic guidance method. The system allows to calculate the position of the drilling tool by creating artificial magnetic fields at the surface. The strength and direction of the generated field are detected by the instrumentation equipping the drill string, and transmitted in real time to the steering engineer. Every single hole shall be planned in advance, and the spatial coordinates of the various surveys shall be compared to the theoretical position to decide the need of a correction. The accuracy requested is plus/minus 30 cm.

Due to the extremely high grade of fracturation of the rock, a downstage grouting method is required in some zones. The holes are drilled until the circulation of the holes can be efficiently maintained. As soon as the flushing of the cuttings cannot be granted, the hole is stopped and grouted. After hardening, the hole is re-drilled.

The procedure is repeated until reaching the design length. Special expansive cement mixture are used to prevent over-grouting due to the highly permeable rock due to the fissures, or to the possibility that the grout by-passes into the waste mass.

The first stage of rough injection, is followed by a second stage aiming to improve the waterproofing of the main fissures and to treat the smallest ones.

To this purpose MPSP (Multiple Packer Sleeved Pipe System) formed by 2″ steel tubes are inserted

Figure 10. Rigs drilling for grouting.

Figure 11. Fractures grouted (borehole camera).

in the boreholes and grouted with high penetration cement and silica mixes.

The result obtained is checked both with permeability test (Lugeon test) and systematic use through of borehole camera inspections. Figure 10 shows efficaciously the good result obtained with fissures completely grouted with cement (grey) and silica (white) mix.

The work is planned to be mostly completed at the end of 2010.

5 CONCLUSIONS

The technology of directional drilling has recently been successfully used for a number of challenging projects in a variety of conditions.

The flexibility of the system allowed to find a solution to difficult geotechnical problems where accuracy is a paramount, proving once more that the merging of the knowledge from one sector to other can be beneficial.

Particularly the Manfredonia dumps case is an original and innovative example of how to solve the problem to isolate a contaminated area with reasonable cost and without touching the waste mass.

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